Susquehanna River Basin Flow Monitoring Network

Technical Summary – 2013

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INTRODUCTION

The Susquehanna River is the largest river in the Atlantic Ocean drainage that is entirely contained within the borders of the United States. The mainstem Susquehanna River and its tributaries constitute more than 49,000 river miles and drain an area of 27,150 square miles encompassing portions of New York, Pennsylvania, and Maryland. The Susquehanna River Basin (basin) is considered a largely water-rich area receiving an average of a little over 40 inches of rainfall annually (SRBC, 2008). The groundwater and surface water resources of the basin are used to meet the demands of a diverse and sometimes conflicting group of users, including drinking water suppliers, wastewater treatment plants, electric power generators, resource extraction industries, recreation groups, and the flora and fauna native to the region.

Despite its abundant water resources, the Susquehanna River Basin is vulnerable to water shortages due to a rapidly increasing human population and threats from a changing climate. As water demands increase to satisfy the drinking water and energy production needs of a growing population, it becomes more challenging to manage water resources to avoid shortages and conflicts. Healthy, functional ecosystems are essential for supporting the basin's many water uses. Water quantity and quality are interdependent and equally important to the integrity of aquatic ecosystems which, when managed properly, are capable of providing adequate quantities of high quality water for both ecological and human uses.

Floods and droughts are natural features of river ecosystems and often occur on a relatively predictable basis (Lake, 2003). The Susquehanna River Basin is one of the country's most flood-prone areas, due in part to its moisture-rich climate, ample groundwater and surface water resources, and high degree of runoff from developed areas. Minor and moderate flooding generally occurs every year somewhere in the basin and major floods have been recorded in all seasons (SRBC, 2008). Major floods are most frequent in the early spring as a result of heavy rainfall on top of snowpack, and in the late summer when tropical storms or the remnants of hurricanes pass through the region. Significant droughts are also a feature of the basin, the most recent occurring in 2002. Many watersheds in the basin experience substantial surface runoff due to steep topography, complex geology, and/or impervious surfaces, and are highly dependent on aquifer storage to sustain streamflows during drought events. Climate change predictions include an increase in the frequency and severity of heavy rainfall with subsequent runoff and flooding, as well as an increase in the frequency of summer droughts. Current trends towards reduced snowfall and increased rainfall in the winter months may result in insufficient spring groundwater recharge and subsequent decreases in surface water availability heading into the dry summer months. Changing climatic conditions coupled with an ever-increasing demand for water pose a serious threat to the ecological integrity of the Susquehanna River and its tributaries.

Streamflow is often referred to as the "master" variable affecting river ecosystems at every level, from small-scale hydraulic conditions on the surface of an individual cobble to channel dimensions at the watershed scale (Hart and Finelli, 1999). Instream habitat is heavily influenced by flow-mediated processes, especially the movement of water and sediment within the stream channel and between the channel and floodplain (Poff and others, 1997). The natural flow regime of a stream varies in response to climate, topography, geology, land use, soils, and longitudinal position within the river network (Poff and Zimmerman, 2010). The magnitude, duration, seasonal timing, and predictability of major flow events, both low and high, are unique to individual river systems. Stream-dwelling organisms have adapted behavioral mechanisms and life history strategies in direct response to the natural flow regimes of their native rivers (Lytle and Poff, 2004). Important life cycle events such as reproduction and migration are often closely tied to seasonal low or high flows. Understanding and maintaining natural flow regimes is therefore critical to conserving the native biodiversity of freshwater systems, particularly in the face of the challenges posed by a changing climate.

FLOW MONITORING IN THE SUSQUEHANNA RIVER BASIN

Recently, The Nature Conservancy (TNC), in conjunction with the Susquehanna River Basin Commission (SRBC) and the U.S. Army Corps of Engineers, conducted an Ecosystem Flow Study that culminated in a set of flow recommendations intended to protect the biological communities and key ecological processes of the Susquehanna River and its tributaries (DePhilip and Moberg, 2010). A critical finding of this study is that ecosystem flow needs are naturally seasonal, and that water managers should impose restrictions on water withdrawals based upon seasonal rather than annual flow recommendations. This finding provided the impetus and context for revision of SRBC's Policy No. 2003-01, *Guidelines for Using and Determining Passby Flows and Conservation Releases for Surface-Water and Ground-Water Withdrawal*

Approvals, previously adopted in 1993. SRBC Policy No. 2012-01, *Low Flow Protection Policy Related to Withdrawal Approvals*, was adopted in December 2012. Instead of a single annual passby flow/conservation release value for low protection, Policy No. 2012-01 outlines a series of seasonal or monthly flow values that more accurately reflect seasonal variability with respect to streamflow and associated ecosystem needs.

TNC's flow recommendations for the Susquehanna River Basin were developed through expert consultation supported by published literature and existing studies rather than quantitative analyses (DePhilip and Moberg, 2010). In addition to ecosystem flow recommendations, the study partners proposed a number of hypotheses regarding anticipated response of species, groups of species, or physical habitat to changing conditions during high and low flows. These hypotheses were intended to direct future quantitative analyses to confirm or revise their flow recommendations. SRBC conducted a Low Flow Monitoring Pilot Study (Pilot Study) in the Juniata River subbasin in 2010 and 2011 (Hutchison, 2012). Data collected during this Pilot Study were used to begin testing some of the hypotheses outlined in the TNC report.

Guided by findings from the Pilot Study, SRBC established a basin-wide Flow Monitoring Network (FMN) in 2012. The purpose of the FMN is to document stream discharge, physical habitat, water quality, and biological communities during the natural low flow period, June 1 through September 30 (DePhilip and Moberg, 2010), in order to identify differences related to streamflow. SRBC staff sample each station in the FMN twice annually: once during a period of higher flow in June or early July and again during a low flow period characterized by the August-September-October mean P95 (ASO P95) flow. P95 flow is defined as the flow exceeded 95 percent of the time. If in a given year ASO P95 does not occur, a second round of sampling will still be conducted after September 1 to document conditions during a "normal" or "high" flow year.

Both flood control and low flow mitigation planning are ongoing priorities of the SRBC. The FMN is a long-term project with a primary objective of documenting habitat, water quality, and biological conditions associated with various streamflows at stations throughout the New York and Pennsylvania portions of the Susquehanna River Basin. Data collected from the FMN stations will be used to characterize and compare water quality, habitat, and biological communities associated with different flows and to advise management decisions regarding low flow mitigation and passby flows associated with surface water withdrawals. The FMN also provides sentinel stations for monitoring changes to flow regime, habitat, water quality, and biological communities that may occur throughout the Susquehanna River Basin as a result of climate change.

STUDY AREA AND MONITORING NETWORK

The FMN consists of 19 stations in the Pennsylvania and New York portions of the Susquehanna River Basin (Figure 1). The 19 stations are distributed across three Level III ecoregions: six stations are located in the Northern Appalachian Plateau and Uplands, six in the North Central Appalachians, and seven in the Central Appalachian Ridges and Valleys (Omernik, 1987).

The Central Appalachian Ridge and Valley ecoregion is comprised of parallel ridges and valleys formed by folding and faulting events. Land use in the Central Appalachian Ridges and Valleys is mixed and includes forested areas concentrated in the ridges with agricultural and urban areas in the valleys. The dominant geologic materials include sandstone, shale, limestone, dolomite, siltstone, chert, mudstone, and marble. Carbonate terrain is common in this ecoregion, which features many subterranean caves and springs.

The Northern Appalachian Plateau and Uplands ecoregion is characterized by open valleys and low mountains and is the largest of all ecoregions in the Susquehanna River Basin. Land use in this ecoregion is primarily agricultural with some woodland and urban areas. The North Central Appalachian ecoregion is a densely forested upland typified by high hills and low mountains. Land use is primarily forested with numerous state forests and game lands located throughout the ecoregion. Resource extraction, including logging, mining, and oil and gas development, is common in the North Central Appalachians. Despite widespread detrimental impacts from abandoned mine drainage (AMD) and atmospheric deposition, some of the basin's most pristine streams and forests are located in this ecoregion, making it a destination for tourists and outdoor enthusiasts. Both the Northern Appalachian Plateau and Uplands and the North Central Appalachians contain unglaciated and glaciated regions and have similar underlying geologic materials, including shale, siltstone, sandstone, and conglomerate.

The FMN focuses on streams in highly forested watersheds in an attempt to isolate natural from anthropogenic impacts to flow. Specific station selection criteria were identified for inclusion in the network, including:

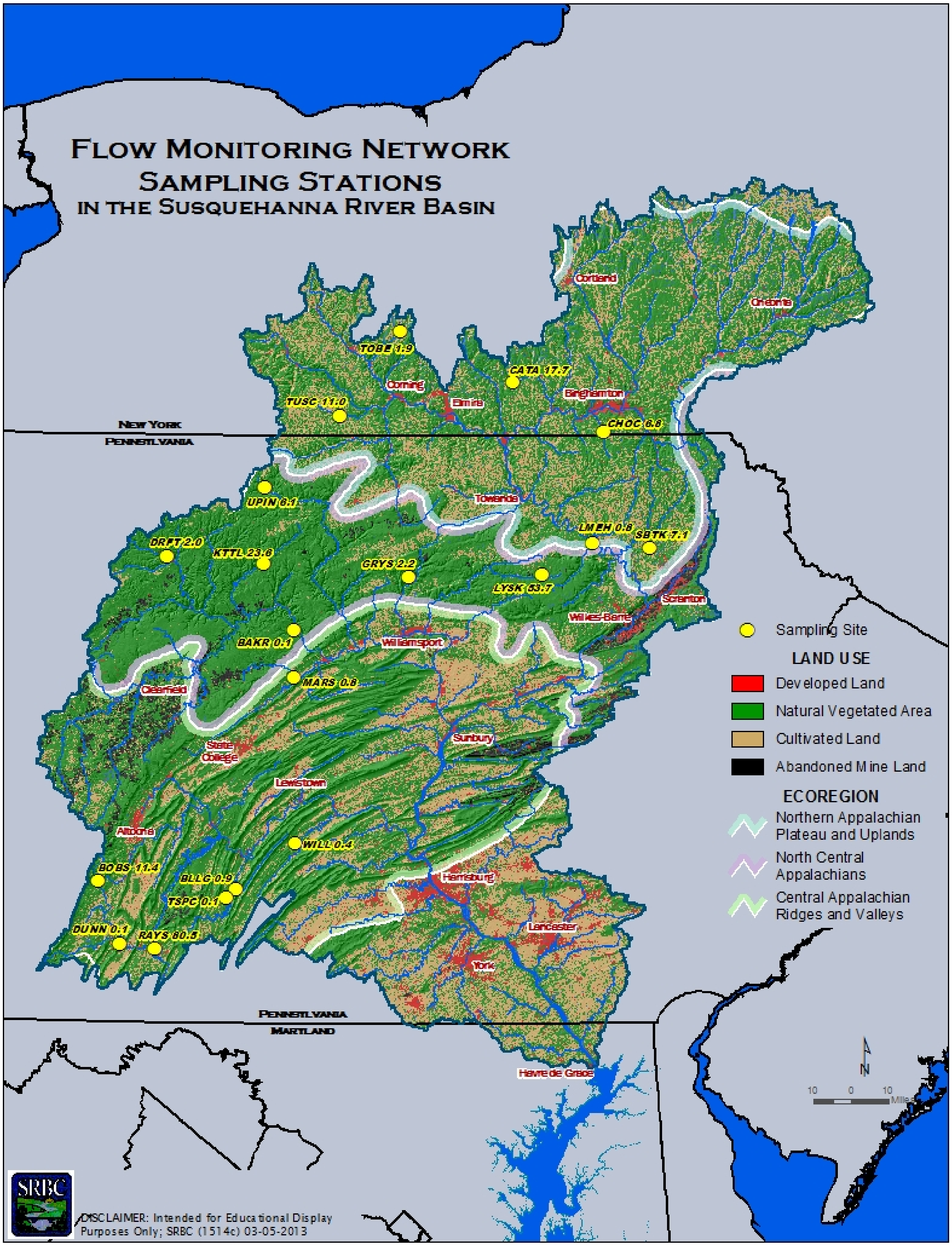

Figure 1. Location of the Flow Monitoring Network Sampling Stations in the Susquehanna River Basin

- Land use – high percentage of forested lands (greater than 70 percent forested in the North Central Appalachian and Central Appalachian Ridge and Valley ecoregions and greater than 40 percent forested in the Northern Appalachian Plateau and Uplands);
- Non-impaired or minimally impaired waters with special consideration given to streams with High Quality (HQ) or Exceptional Value (EV) designations;
- Presence of non-impaired or minimally impaired biological communities (based on historic SRBC field surveys);
- Drainage area – per ecoregion, at least two stations each with drainage area less than 25 square miles, 25 – 49 square miles, and greater than 50 square miles.

Five stations, all located in the Central Appalachian Ridges and Valleys, were carried over from the Low Flow Monitoring Pilot study. The station on Standing Stone Creek (STST 26.8) was sampled during the Pilot study and in 2012, but was replaced by a station on Marsh Creek (MARS 0.8) in 2013. Twelve of the FMN stations overlap with stations that are part of SRBC's Remote Water Quality Monitoring Network (RWQMN). The RWQMN stations are equipped with real-time data sondes that continuously record and report temperature, pH, conductance, dissolved oxygen, turbidity, and water depth. For a list of FMN station names, location descriptions, geographic coordinates, drainage areas, percentage of forested and agricultural lands, and designated uses, see Appendix A. Stations that are part of the RWQMN are also noted in Appendix A.

METHODS

Data Collection

Sampling design and methods employed in 2013 closely followed those outlined in the Flow Monitoring Network Technical Summary – 2012 (Hutchison, 2013). Sampling reaches were established in 2012 and were sampled again in 2013. Reach length was equal to ten times the average wetted width of the stream channel, plus or minus 10 meters, with a minimum length of 100 meters and a maximum length of 400 meters. SRBC staff completed two rounds of sampling at the FMN stations in 2013 during the natural low flow period. The first round of sampling (Round 1) took place between June 4 and June 25 during summer baseline flow conditions. DUNN 0.1 (Dunning Creek) was not sampled during Round 1 due to high turbidity and extremely poor visibility originating from multiple upstream bridge construction projects. SRBC completed a second round of sampling (Round 2) between September 4 and September 26. All 19 stations were sampled during Round 2.

Staff monitored flow conditions prior to the start of the sampling period in June and between the sampling rounds by accessing real-time streamflow data from the U.S. Geological Survey (USGS) web site (http://waterwatch.usgs.gov). Parameters monitored during each sampling round included stream discharge, physical habitat, water quality, macroinvertebrate and fish communities, and periphyton biomass.

Stream Discharge

During each sampling round, SRBC staff measured stream discharge (flow) using a FlowTracker and standard USGS procedures (Buchanan and Somers, 1969). Discharge was not measured at MARS 0.8 because this station is located at a USGS gaging station.

InSitu, Inc. Level TROLL pressure transducers were installed at 16 FMN stations in 2012 in order to continuously record water depth. Pressure transducers were not installed at MARS 0.8, DUNN 0.1, or RAYS 80.5 (Raystown Branch Juniata River) due to the proximity of these stations to USGS gaging stations. The pressure transducers at ten stations report real-time data via the RWQMN satellite system. Data from the other six pressure transducers are stored internally and downloaded at regular intervals by SRBC staff. Instantaneous discharge measurements taken at 6 – 8 week intervals are paired with water depth measurements from the pressure transducers and used to build rating curves.

Habitat

Habitat conditions were assessed using a modified version of the U.S. Environmental Protection Agency's (USEPA's) Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers (RBP III) (Plafkin and others, 1989; Barbour and others, 1999). Physical stream characteristics relating to substrate, pool, and riffle composition, flow status, shape of the channel, conditions of the banks, and the riparian zone were rated on a scale of 0 – 20, with 20 being optimal. Other observations were noted regarding recent precipitation, dominant substrate material composition, surrounding land use, and any other relevant features of the landscape. See Appendix B for a complete list and description of the habitat condition factors assessed for this project.

Wolman pebble counts were added to the FMN sampling methods in 2013 in order to characterize the stream bed surface sediments (Wolman, 1954) and quantify differences between sampling periods. Ten transects were distributed throughout the sample reach according to the proportion of major habitat types (i.e., riffle, pool, run/glide). For example, if a reach consisted of 30 percent pools and 70 percent riffles, then three transects would be located in pools and seven in riffles. At each transect, staff measured the intermediate axes of ten pebbles using a gravelometer. Pebbles were randomly selected using a step-toe procedure. Pebble count transects were marked with flagging and the distance between each transect and the bottom of the reach was measured to insure that the same transects were sampled during both sampling rounds. Staff also recorded wetted width and habitat type at each transect.

Water Quality

Field chemistry parameters were measured at the time of sampling and water samples were collected for laboratory analyses. Table 1 lists all water quality parameters measured and their associated levels of concern based on current state or federal standards, background levels for uninfluenced streams, or references for aquatic life tolerances. A handheld multi-probe YSI sonde was used to simultaneously collect all field chemistry parameters (stream temperature, conductivity, pH, and dissolved oxygen). The probes were rinsed with distilled water and sample water prior to collection of water quality data, and calibrations were conducted as detailed in the Quality Assurance Project Plan (Quality Assurance/Work Plan, Document Control Number SRBC – QA049). Water samples for laboratory analyses were collected using depth-integrated sampling methods (Guy and Norman, 1969) and kept on ice until delivery to ALS Environmental in Middletown, Pa. SRBC staff collected one set of duplicate water samples per sampling round.

Macroinvertebrates

Benthic macroinvertebrates were collected using a modified version of RBP III (Barbour and others, 1999). Sampling was conducted in the best available riffle/run habitat using a D-frame kick net with 500-micron mesh. Samples consisted of a composite of six kicks with each kick disturbing approximately one square meter of substrate immediately upstream of the net for a period of one minute. Samples were preserved with 95-percent denatured ethyl alcohol and returned to SRBC's lab. The sample was then subsampled following procedures outlined in the Pennsylvania Department of Environmental Protection's (PADEP's) benthic macroinvertebrate

Table 1. Water Quality Levels of Concern for Parameters Measured at Flow Monitoring Network Stations

Parameters	**Level of Concern**	**Reference Code**	**Reference**
Based on state water quality standards:			
Temperature	> 30.5 ºC	a	a. http://www.pacode.com/secure/data/025/chapter93/s93.7.html
Dissolved Oxygen	< 4 mg/l	a	b. http://www.pacode.com/secure/data/025/chapter93/s93.8c.html
pH	< 6.0	a	c. http://www.dec.ny.gov/regs/4590.html#16132
Alkalinity	< 20 mg/l	a	d. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.03-3.htm
Total Chloride	> 250 mg/l	a	
Total Dissolved Solids	> 500 mg/l	c	
Total Sulfate	> 250 mg/l	a	
Total Iron	> 1500 µg/l	a	
Total Manganese	> 1000 µg/l	a	
Total Aluminum*	> 750 µg/l; > 100 µg/l	b; c	
Total Magnesium	> 35 mg/l	c	
Total Sodium	> 20 mg/l	c	
Total Suspended Solids	> 25 mg/l	a	
Turbidity	> 50 NTU	d	
Based on background levels or aquatic life tolerances:			
Conductivity	> 800 µmhos/cm	e	e. http://www.uky.edu/WaterResources/Watershed/KRB_AR/wq_standards.htm
Total Nitrogen	> 1 mg/l	f	f. http://water.usgs.gov/pubs/circ/circ1225/images/table.html
Total Nitrate/Nitrite-N	> 0.6 mg/l	f	g. http://www.uky.edu/WaterResources/Watershed/KRB_AR/krww_parameters.htm
Total Phosphorus	> 0.1 mg/l	g	h. Hem (1970)
Total Orthophosphate	> 0.02 mg/l	f	i. Based on archived data at SRBC
Total Organic Carbon	> 10 mg/l	h	
Total Hardness	> 300 mg/l	g	
Acidity	> 20 mg/l	i	
Calcium	> 100 mg/l	i	

*PA sites use > 750 µg/l standard for aluminum; NY sites use > 100 µg/l standard for aluminum index of biotic integrity (PADEP, 2012). Most insect taxa were identified to genus. Midges were identified to the family level of Chironomidae. Non-insect taxa (i.e., worms, mollusks, and mites) were identified to family, order, class, or phylum depending on available keys.

Fish

The fish community was sampled using methods adapted from the RBP III manual (Barbour and others, 1999) and PADEP's draft fish index of biological integrity. Electrofishing was conducted in wadeable reaches using either a backpack electroshocker or a tow barge unit, depending on the size of the stream. Three electrofishing passes were made per station, and all accessible habitats in the stream reach were sampled. All fish caught were identified to species and enumerated. The first 50 individuals of each game species were also measured (total length). All fish were returned to the stream after processing unless there was a question regarding identification, in which case the specimen was preserved in 10-percent formalin and returned to the laboratory for identification.

Periphyton

Periphyton were collected for determination of chlorophyll-a (chl-a) concentration, which may be used as a surrogate for biomass. Collection methods followed USEPA's National River and Stream Assessment Protocols (USEPA, 2007). Periphyton were sampled by removing natural rocks from the stream bed at each of 11 transects established throughout the sampling reach. Attached periphyton from a delimited area on the surface of each rock were scraped and rinsed into a bottle. A 50-milliliter aliquot of water from the rinse bottle was vacuum filtered onto a 4.7-centimeter, EPM 2000 filter paper, chilled on ice, and shipped to the PADEP lab in Harrisburg, Pa., for analysis of chl-a concentration.

Data Analysis

Percent change in stream discharge between the two sampling rounds and ASO flow exceedance percentiles at the reference gages at the time of sampling were calculated. Preliminary stage-discharge rating curves were established using data collected through December 31, 2013 for the 16 stations equipped with pressure transducers (Sauer, 2002).

Table 2. Wentworth Size Classes used to Characterize Wolman Pebble Count Measurements

General Description	Particle Size Class	Size Range (mm)
SILT/CLAY	Silt/Clay	< 0.06
SAND	Sand	0.06 - 2.0
GRAVEL	Very Fine	2.0 - 4.0
	Fine	4.0 - 6.0
	Fine	6.0 - 8.0
	Medium	8.0 - 11.0
	Medium	11.0 - 16.0
	Coarse	16.0 - 22.0
	Coarse	22.0 - 32.0
	Very Coarse	32.0 - 45.0
	Very Coarse	45.0 - 64.0
COBBLE	Small	64.0 - 90.0
	Medium	90.0 - 128.0
	Large	128.0 - 180.0
	Very Large	180.0 - 256.0
BOULDER	Small	256.0 - 1024.0
	Large	> 1024.0

Habitat assessment scores from the modified RBP III were used to classify each station into a habitat condition category. Scores from 171 to 220 were designated excellent. A habitat score from 116 to 170 indicated supporting conditions, scores between 61 and 115 designated partially supporting habitat, and a score less than 60 was deemed non-supporting. Individual pebbles measured during the modified Wolman pebble counts were categorized using Wentworth size classes (Table 2) and converted into percentages by size class. Cumulative particle size distributions were calculated for each sampling period and compared.

Water quality was assessed by comparing field and laboratory parameter data to water quality levels of concern (see Table 1).

Non-metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity (Bray and Curtis, 1957) was used to visually examine relative similarity of fish and macroinvertebrate communities between stations and sampling periods. NMDS functions by mapping community dissimilarities based on taxa abundances into *n*-dimensional ordination space (Clarke, 1993). All ordinations were two-dimensional and the distances between points on the plot approximated the degree of dissimilarity in communities. Samples that plotted distantly from one another may have had few taxa in common or abundances of shared taxa may have been substantially different. Samples plotting close together had more shared taxa with similar abundances. Stress values were obtained for each ordination. Stress values less than 0.05 indicate an excellent representation with no potential for misinterpretation, values between 0.05 and 0.1 correspond to a good representation with a small chance of misinterpretation, and values between 0.1 and 0.2 indicate a potentially useful representation but with potential for misinterpretation. Stress values greater than 0.3 indicate the points are close to being arbitrarily placed in the ordination space (Clarke and Warwick, 2001). The metaMDS function in the vegan package of the R software environment was used to complete NMDS ordination (Oksanen and others, 2011).

Macroinvertebrate and fish data were used to calculate biological metrics assessing various aspects of the assemblages. A complete list and description of macroinvertebrate and fish metrics calculated can be found in Table 3. Fish and macroinvertebrate metrics were taken primarily from Barbour and others (1999) and from TNC's report outlining ecosystem flow requirements for the Susquehanna River Basin (DePhilip and Moberg, 2010). The functional trait and general assemblage metrics taken from the TNC ecosystem flows have been hypothesized to be sensitive to flow-related changes in macroinvertebrate and fish communities.

The PADEP Benthic Index of Biotic Integrity (IBI) was also calculated for macroinvertebrate samples. The IBI is a multimetric index that measures the degree to which a set of community-level biological attributes differ at sites of interest compared to a "reference" condition. In this context, reference condition refers to a state of natural biotic structure and function in the absence of significant human disturbance or alteration (Stoddard and others, 2006). PADEP's IBI considers streams with drainage area less than 25 square miles, between 25 and 50 square miles, and greater than 50 square miles separately when calculating IBI scores. Score interpretation is the same across drainage area size classes. Information from the six IBI component metrics is incorporated into a single measure of overall biological condition with scores ranging from zero to 100. For macroinvertebrate samples collected between June and September, IBI scores less than 43 indicate aquatic life use (ALU) impairment. Samples scoring greater than or equal to 43 are subject to four screening questions before ALU attainment/impairment can be determined. The first screening question addresses absence of mayflies, stoneflies, and/or caddisflies, the second addresses scores for the Beck's Index and Percent Sensitive Individuals metrics, the third question deals with the ratios of tolerant to intolerant taxa, and the fourth flags signatures of acidification (i.e., low mayfly abundance/diversity and high abundance of acid-tolerant stoneflies). If a sample fails any of the screening questions, it may be considered impaired without compelling reason otherwise (PADEP, 2012).

Table 3. Description of Biological Metrics Calculated Using Data Collected At the Flow Monitoring Network Stations in 2012

Metrics	**Description**
Macroinvertebrates	
Index of Biotic Integrity (IBI)	Multimetric biotic index developed by PADEP (2012)
Taxa Richness*	Total number of macroinvertebrate taxa identified
EPT Taxa Richness*	Total number of individuals from orders Ephemeroptera, Plecoptera, and Trichoptera
% Sensitive (PTV ≤ 3)*	Percentage of individuals that have Pollution Tolerance Values (PTV) 0 – 3
Shannon Diversity Index*	Measures taxonomic richness and evenness of individuals across taxa of a subsample
Hilsenhoff Biotic Index*	Calculated as an average of the number of individuals in a subsample weighted by PTVs
Beck's Index (version 3)*	Taxonomic richness and tolerance metric weighted by PTVs
% Dominant	Percentage represented by the dominant taxon
% Multivoltine	Percentage of multivoltine (multiple generations per year) individuals
% Desiccation Tolerant	Percentage of desiccation tolerant individuals
% Strong Adult Flying Ability	Percentage of individuals having strong adult flying ability
% Common/Abundant in Drift	Percentage of individuals common or abundant in drift
% Strong Swimmers	Percentage of individuals with strong swimming ability
% Small-bodied	Percentage of small-bodied individuals
% Free-living	Percentage of taxa not utilizing cases or other forms of substrate attachment
% Erosional	Percentage of erosional individuals
% Obligate Depositional	Percentage of obligate depositional individuals
% Shredders	Percentage of shredder individuals
% Herbivores	Percentage of herbivore taxa
% Collector-Filterers	Percentage of collector-filterer individuals
% Predators	Percentage of predator individuals
% Eurythermal	Percentage of eurythermal (wide temperature range) individuals
% Cold Stenothermal	Percentage of cold stenothermal (narrow temperature range) individuals
% Burrowers	Percentage of burrower individuals
Fish	
Species Richness	Total number of fish species identified
% Tolerant	Percentage of tolerant individuals
% Intolerant	Percentage of intolerant individuals
% Dominant	Percentage of assemblage represented by the dominant species
% Cyprinids	Percentage of assemblage represented by Cyprinidae (minnows)
% Piscivores	Percentage of piscivorous individuals
% Insectivores	Percentage of insectivorous individuals
% Generalists	Percentage of generalist individuals
% Herbivores	Percentage of herbivorous individuals
% Coldwater	Percentage of brook trout, brown trout, rainbow trout, sculpin
% Riffle Obligates	Percentage of margined madtom, longnose dace, central stoneroller, fantail darter
% Riffle Associates	Percentage of white sucker, shorthead redhorse, northern hogsucker, walleye

*IBI component metric

Six stations in the FMN are designated high-quality (HQ) or exceptional value (EV) waters (25 Pa. Code § 93.9), including WILL 0.4 (Willow Creek), BOBS 11.4 (Bobs Creek), GRYS 2.2 (Grays Run), UPIN 6.1 (Upper Pine Creek), BAKR 0.1 (Baker Run), and KTTL 23.6 (Kettle Creek). The ALU assessment process for streams with special protection designated uses differs slightly from the standard process described above (PADEP, 2012). First, PADEP will only make assessment decisions for HQ and EV based on samples collected November to May because macroinvertebrate taxonomic richness is highest during this time period. Any sample from an HQ or EV stream that scores less than 63 on the IBI is considered impaired without compelling reason otherwise. Determination of ALU attainment for HQ and EV streams is made by comparing the current IBI score to a baseline score from previous surveys, when available. Samples scoring more than 10 points below the baseline score are considered impaired. Because the FMN stations were not sampled between November and May, ALU attainment cannot be reliably determined for HQ and EV stations. Therefore, IBI scores for these stations serve primarily as points of comparison between sampling rounds.

Periphyton biomass was assessed using chl-a concentration as a surrogate. Chl-a concentrations greater than 10 $\mu g/cm^2$ are indicative of algal growth at nuisance levels (Welch and others, 1988) and chl-a greater than 20 $\mu g/cm^2$ indicates eutrophic conditions (Paul, 2012).

RESULTS AND DISCUSSION

Stream Discharge

Water year is defined as the 12-month period from October 1 of a given year through September 30 of the following year and is designated by the calendar year in which it ends. The Susquehanna River Basin received 36.5 inches of precipitation over the course of water year 2013 compared to an annual average of 40.8 inches (NOAA, 2014). June 2013 was somewhat wetter than average while August and September 2013 were slightly drier (Figure 2). For the most part, these conditions are reflected in the streamflow data collected at the FMN stations (Table 4). The majority of stations showed a reduction in streamflow between sampling rounds; however, flows were higher during Round 2 at two stations in the Northern Appalachian Plateau and Uplands ecoregion. Percent change in streamflow ranged from a 91 percent reduction at TSPC 0.1 (Three Springs Creek) and LYSK 53.7 (Loyalsock Creek) to 58 percent increase at SBTK 7.1 (South Branch Tunkhannock Creek).

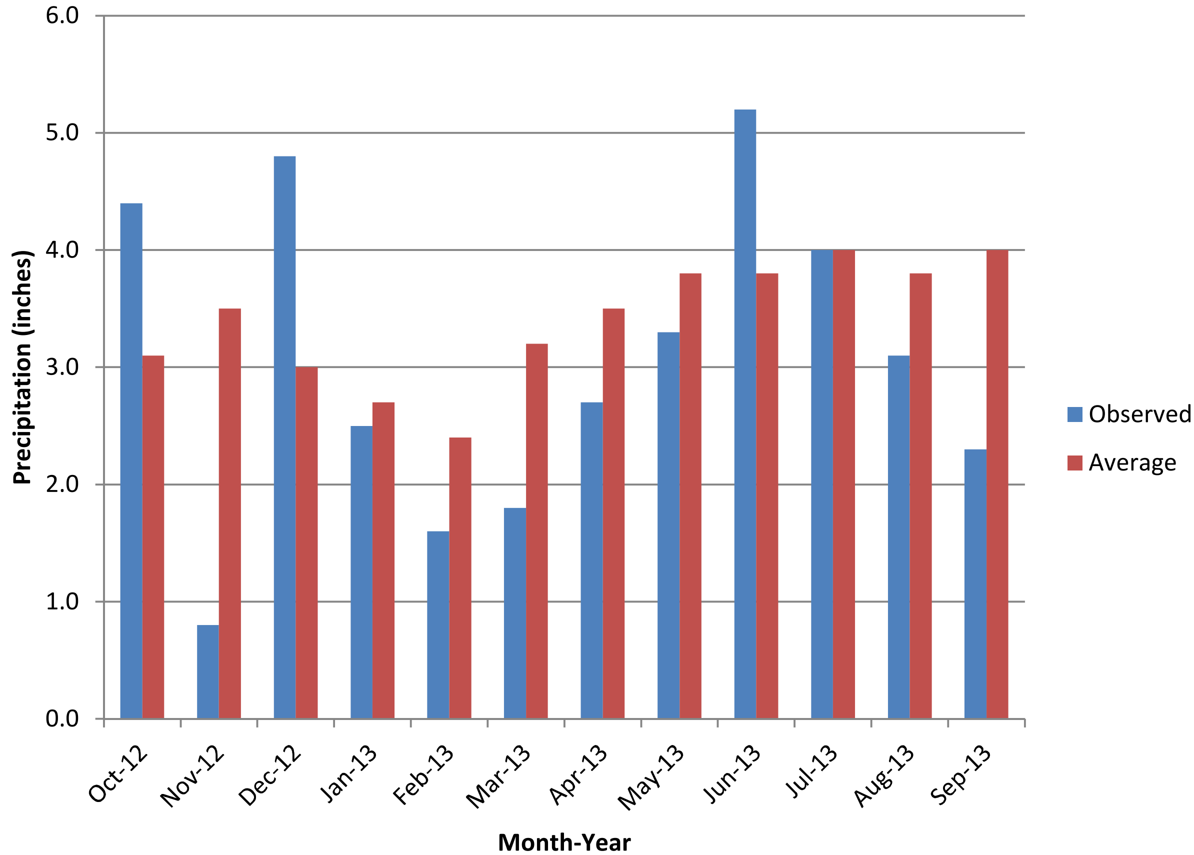

Figure 2. Observed versus Average Precipitation in Inches for the Susquehanna River Basin during Water Year 2013 (October 1, 2012 to September 30, 2013)

Flows were lower during Round 2 at all six stations in the Central Appalachian Ridges and Valleys ecoregion. When Round 2 sampling occurred at TSPC 0.1 and BLLG 0.9 (Blacklog Creek), the ASO mean exceedance percentile at the Aughwick Creek USGS gage was 92 (Table 4). Likewise, the flow at the Tuscarora Creek gage during Round 2 sampling at WILL 0.4 corresponded to ASO P92. Four stations in the Northern Appalachian Plateau and Uplands, including LMEH 0.8 (Little Mehoopany Creek), CATA 17.7 (Catatonk Creek), CHOC 6.8 (Choconut Creek), and TUSC 11.0 (Tuscarora Creek), were sampled at a lower flow during Round 2. Flows were higher during Round 2 at TOBE 1.9 (Tobehanna Creek) and SBTK 7.1. All stations in the North Central Appalachians had lower flows during Round 2. The Round 2 flow at the Lycoming Creek gage, which is the reference for GRYS 2.2 (Grays Run), corresponded to ASO P94.

Table 4. Measured Flow, Percent Change in Flow, and Flow and August-September-October Mean Flow Exceedance Percentile at Reference Gages at Time of Sampling

Station Name	Date Sampled	Flow (cfs)	Percent Change in Flow	Reference Gage	Flow at Reference Gage (cfs)	ASO Mean Exceedance Percentile
Central Appalachian Ridges and Valleys						
WILL 0.4	06/17/13 09/11/13	6.0 1.4	-78%	Tuscarora Creek (01566000)	103.0 13.0	19 92
BOBS 11.4	06/19/13 09/04/13	27.3 4.6	-83%	Dunning Creek (01560000)	317.0 46.0	4 29
TSPC 0.1	06/17/13 09/11/13	8.2 0.8	-91%	Aughwick Creek (01564500)	76.0 7.1	17 92
MARS 0.8	06/12/13 09/16/13	14.0 2.2	-84%	Marsh Creek (01547700)	14.0 2.2	27 84
BLLG 0.9	06/17/13 09/11/13	34.8 3.4	-90%	Aughwick Creek (01564500)	76.0 7.1	17 92
DUNN 0.1	n/a 09/04/13	n/a 51.0	n/a	Dunning Creek (01560000)	n/a 53.0	n/a 25
RAYS 80.5	06/24/13 09/05/13	172.1 103.9	-40%	Raystown Branch (01562000)	270.0 174.0	24 45
Northern Appalachian Plateau and Uplands						
LMEH 0.8	06/05/13 09/25/13	1.3 0.4	-72%	Tunkhannock Creek (01534000)	124.0 147.0	40 34
TOBE 1.9	06/04/13 09/24/13	2.0 2.2	15%	Canisteo River (01521500)	7.4 4.8	22 32
CATA 17.7	06/05/13 09/25/13	9.3 8.4	-10%	Fall Creek (04234000)	54.0 103.0	33 17
CHOC 6.8	06/05/13 09/25/13	9.1 6.6	-27%	Tunkhannock Creek (01534000)	128.0 151.0	38 33
TUSC 11.0	06/04/13 09/24/13	6.2 2.1	-66%	Tuscarora Creek (01525981)	14.0 9.3	38 46
SBTK 7.1	06/06/13 09/26/13	19.6 31.1	58%	Tunkhannock Creek (01534000)	116.0 136.0	42 37
North Central Appalachians						
GRYS 2.2	06/19/13 09/10/13	21.6 2.2	-90%	Lycoming Creek (01550000)	188.0 11.0	15 94
UPIN 6.1	06/20/13 09/17/13	2.0 0.3	-85%	Kettle Creek (01544500)	156.0 37.0	13 40
LYSK 53.7	06/20/13 09/10/13	21.9 1.9	-91%	Muncy Creek (01552500)	26.0 5.2	23 67
BAKR 0.1	06/12/13 09/16/13	28.1 3.5	-88%	Young Womans Creek	38.0 3.4	21 86
DRFT 2.0	06/25/13 09/19/13	36.9 11.3	-69%	Driftwood Branch (01543000)	121.0 60.0	26 43
KTTL 23.6	06/25/13 09/17/13	42.1 13.1	-69%	Kettle Creek (01544500)	79.0 36.0	23 41

Rating Curves

In order to improve timing of sampling with target flows and better correlate flow with measured habitat, water quality, and biological parameters, SRBC installed InSitu, Inc. Level TROLL pressure transducers at 16 FMN stations in 2012. These pressure transducers continuously record water depth. Depth measurements, when paired with instantaneous discharge measurements, can be used to build rating curves and provide a continuous streamflow record for each FMN station. The pressure transducers at ten stations report real-time data via the RWQMN satellite system. Data from the remaining six stations are manually downloaded by SRBC at six- to eight-week intervals. Once accurate rating curves are developed for the real-time stations, the need to use USGS gages as references to coordinate sampling rounds will be eliminated. Although the other six transducers cannot act as real-time references, the continuous flow record they will provide can be used to develop correlations between flows at the stations and the best available USGS reference gage, which will improve timing of sampling rounds.

Preliminary rating curves have been developed for each station using depth and flow measurements taken between June 1, 2012 and December 30, 2013. Figure 3 depicts a typical preliminary rating curve developed for the FMN. Rating curve improvement is a high-priority action item for calendar year 2014. SRBC staff will determine what instantaneous flow measurements need to be taken at each station in order to create accurate and useable rating curves to facilitate coordination of FMN sampling efforts beginning in 2015.

Habitat

The FMN stations were selected based on historical records of non-impaired habitat, water quality, and biological conditions observed during previous SRBC field surveys (Buda, 2007; Campbell, 2011; Hintz, 2011). As expected, all stations except CATA 17.7 were categorized as having either excellent or supporting habitat during both sampling rounds in 2013.

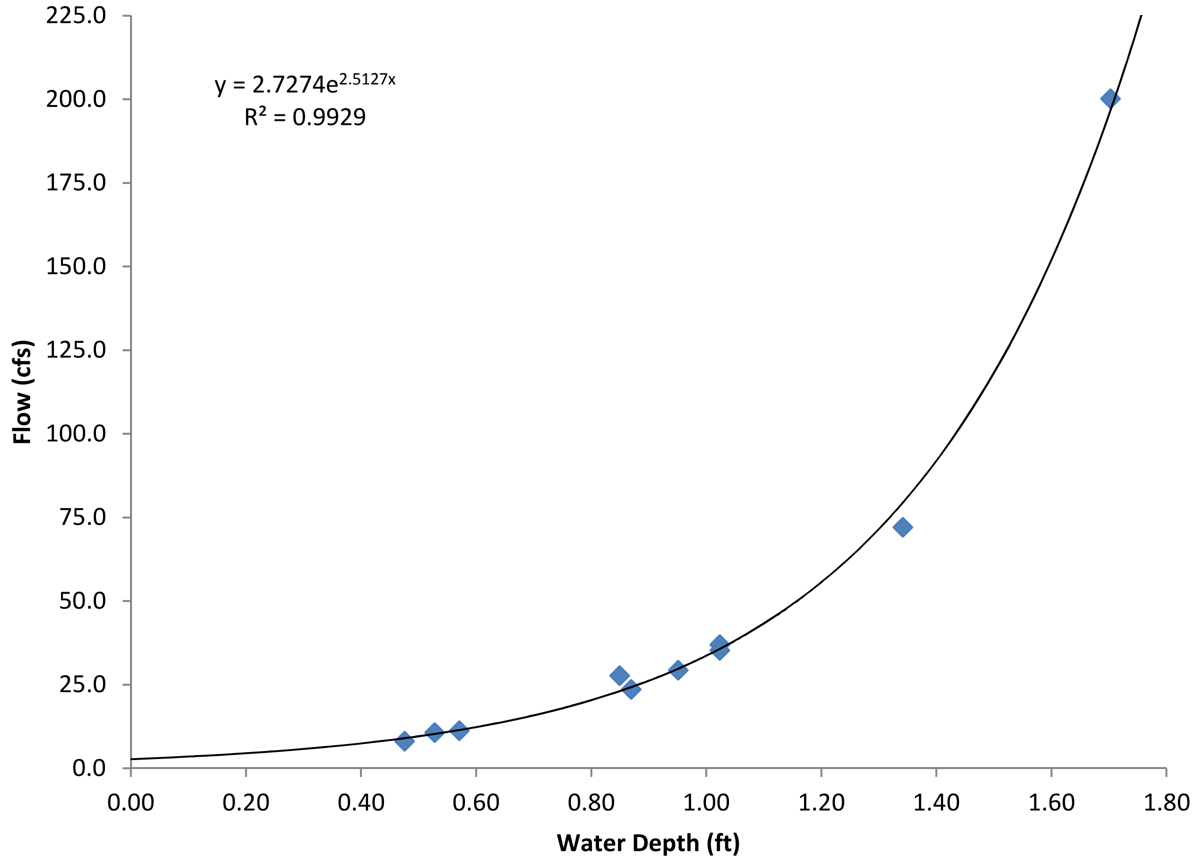

Figure 3. Preliminary Flow Rating Curve for the DRFT 2.0 (Driftwood Branch Sinnemahoning Creek) Flow Monitoring Network Station

All stations in the Central Appalachian Ridge and Valley ecoregion except for BOBS 11.4 were designated as having supporting habitat during both sampling rounds. Habitat at BOBS 11.4 scored excellent during both sampling rounds. All Northern Appalachian Plateau and Uplands stations were designated as supporting during both sampling rounds except for TOBE 1.9, CATA 17.7, and SBTK 7.1. Habitat at TOBE 1.9 was deemed supporting during Round 1 and excellent during Round 2. Flow was 15 percent greater at TOBE 1.9 during Round 2 (Table 4), resulting in increases in scores for habitat condition factors closely related to flow such as instream cover, velocity/depth regimes, and channel flow status. The lowest numerical habitat score, corresponding to a designation of partially supporting, was observed at CATA 17.7 during Round 1. Impacts from agriculture likely drive the low habitat scores at CATA 17.7. Although there is a narrow, mature forested buffer bordering the CATA 17.7 sampling reach, there are crops growing along the right bank and cattle pastured along the left bank, both of which could potentially increase sediment inputs to the stream. This station consistently receives low scores for habitat condition factors related to sedimentation, particularly embeddedness and sediment deposition. Habitat was designated supporting at CATA 17.7 during Round 2 despite a 10 percent reduction in streamflow compared to Round 1 (Table 4). Habitat was excellent at SBTK 7.1 during both sampling rounds.

Stations located in the North Central Appalachians tended to have better overall habitat than stations located in the other ecoregions, primarily due to the high percentage of forested lands in this ecoregion (see Appendix A). Flows at these stations were an average of 82 percent lower during Round 2 than Round 1, a difference that was reflected in habitat conditions. Four stations, including GRYS 2.2, UPIN 6.1, LYSK 53.7, and DRFT 2.0, had excellent habitat during Round 1 and supporting habitat during Round 2. Decreases in flow-dependent condition factors, including epifaunal substrate, instream cover, velocity/depth regimes, channel flow status, and frequency of riffles during Round 2 accounted for the score differences at these stations. Habitat at BAKR 0.1 and KTTL 23.6 was excellent during both rounds.

Pebble Counts

Stream bed substrates at the FMN stations were characterized during both sampling periods using a modified Wolman pebble count approach (Wolman, 1954). Substrate composition, particularly the percentage of fine sediments (particles with an intermediate axis less than 2mm), has been demonstrated to strongly influence both macroinvertebrate and fish assemblages (Berkman and Rabeni, 1987; Culp and others, 1985). Severe sedimentation reduces substrate heterogeneity and availability of interstitial habitat, both of which are important determinants of macroinvertebrate diversity in lotic systems (Richards and Host, 1994), and can also suffocate the eggs and larvae of gravel-spawning fish (Wood and Armitage, 1997). Sediment deposition occurs under a range of flow conditions. During base flow periods, sedimentation occurs naturally in slow-flowing areas such as pools and along banks, backwater zones, macrophyte beds, and sheltered pockets behind large cobbles and boulders. Periods of low flows can result in increased sedimentation throughout the stream channel due to decreased mobilization of fine particles (Wood and Armitage, 1997).

Substrate composition at the FMN stations was similar across ecoregions and drainage area size classes (Figures 4 – 8). Coarse gravel (11.0 – 64 mm) and cobbles (64 – 300 mm) were dominant while fine sediments made up only a small proportion of the substrate at most stations. The sampling reaches at two stations, WILL 0.4 and RAYS 80.5, featured significant portions of

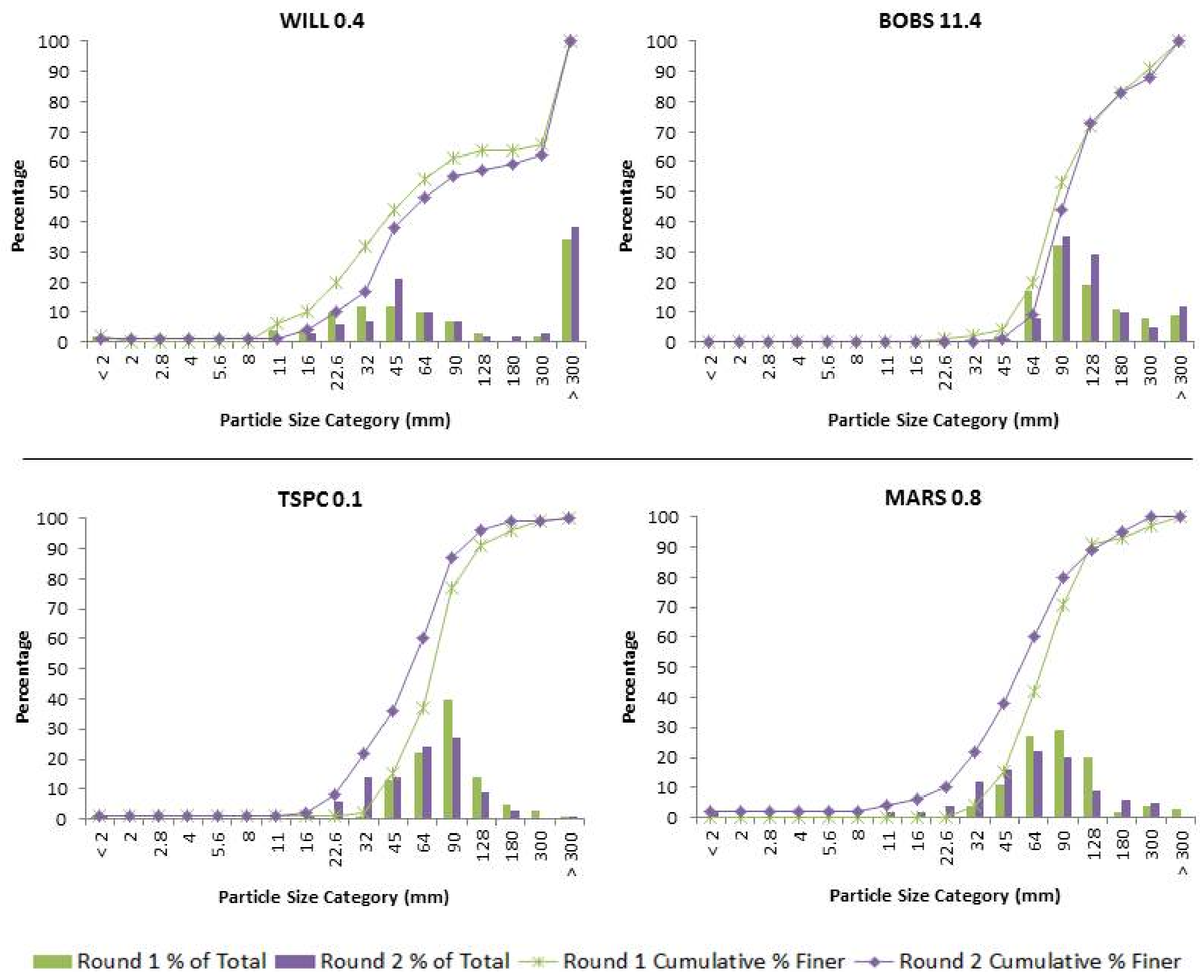

Figure 4. ***Substrate Particle Size Distribution (Percentage of Total and Cumulative Percentage Finer) for WILL 0.4, BOBS 11.4, TSPC 0.1, and MARS 0.8, Comparing Round 1 and Round 2 Pebble Count Data***

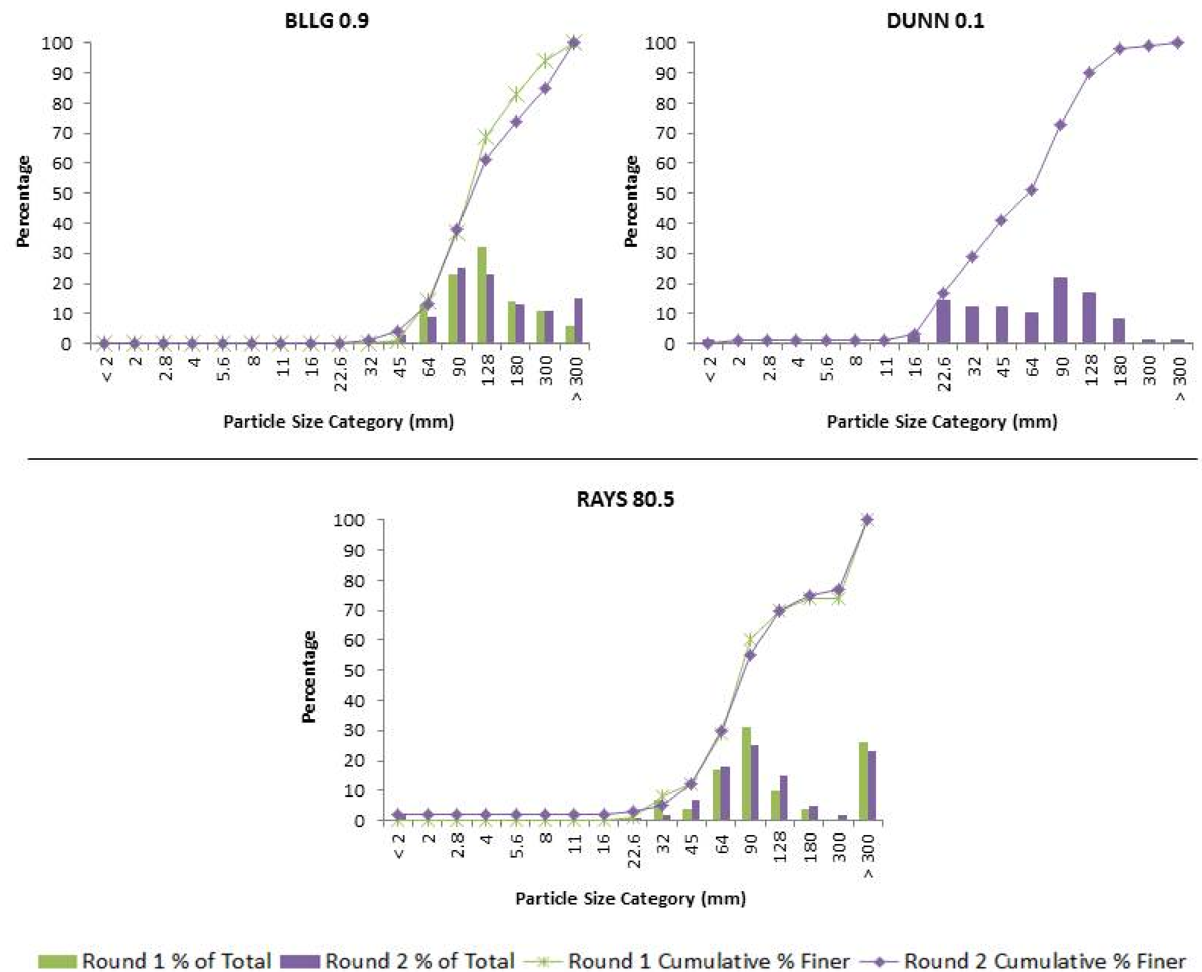

Figure 5. Substrate Particle Size Distribution (Percentage of Total and Cumulative Percentage Finer) for BLLG 0.9, DUNN 0.1, RAYS 80.5, Comparing Round 1 and Round 2 Pebble Count Data

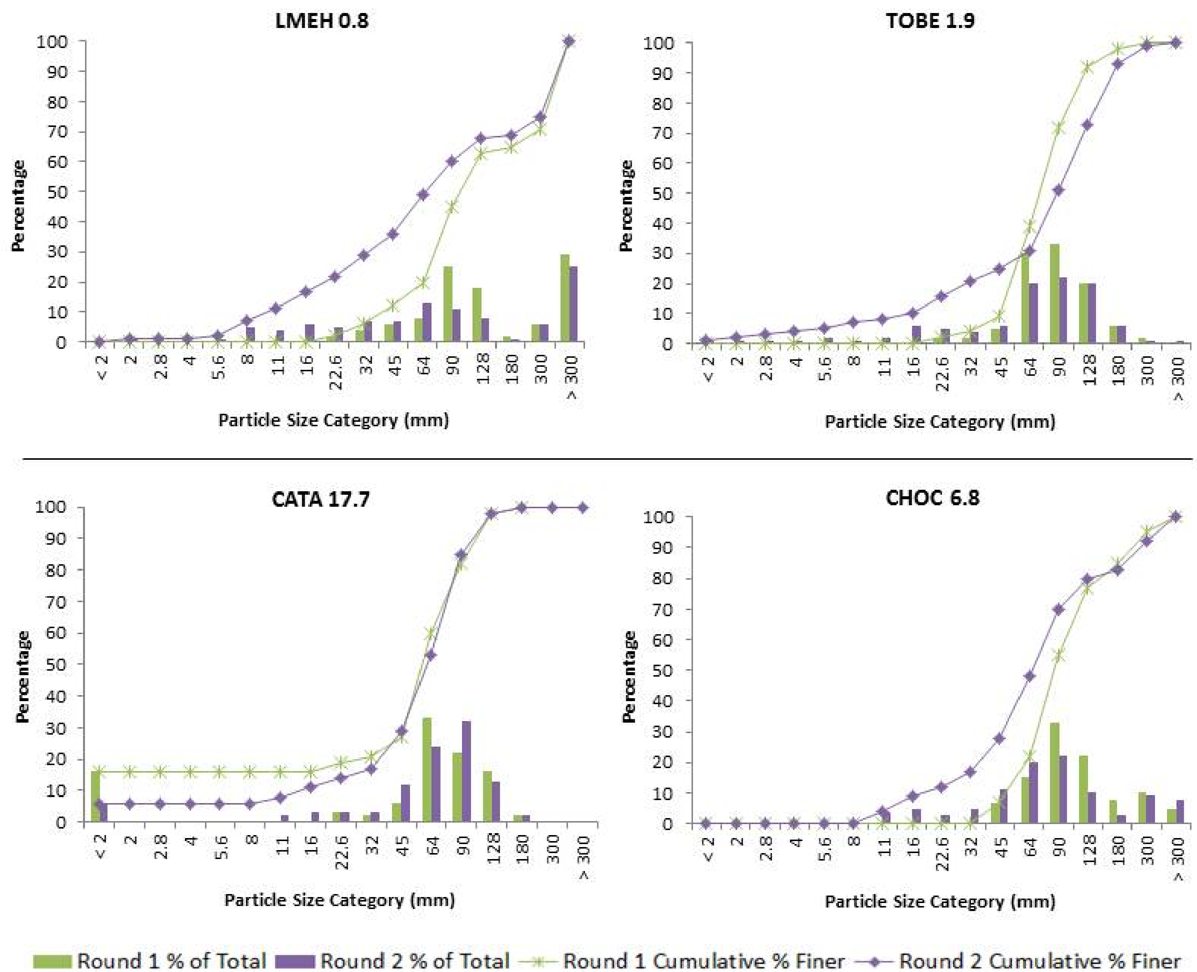

Figure 6. Substrate Particle Size Distribution (Percentage of Total and Cumulative Percentage Finer) for LMEH 0.8, TOBE 1.9, CATA 17.7, and CHOC 6.8, Comparing Round 1 and Round 2 Pebble Count Data

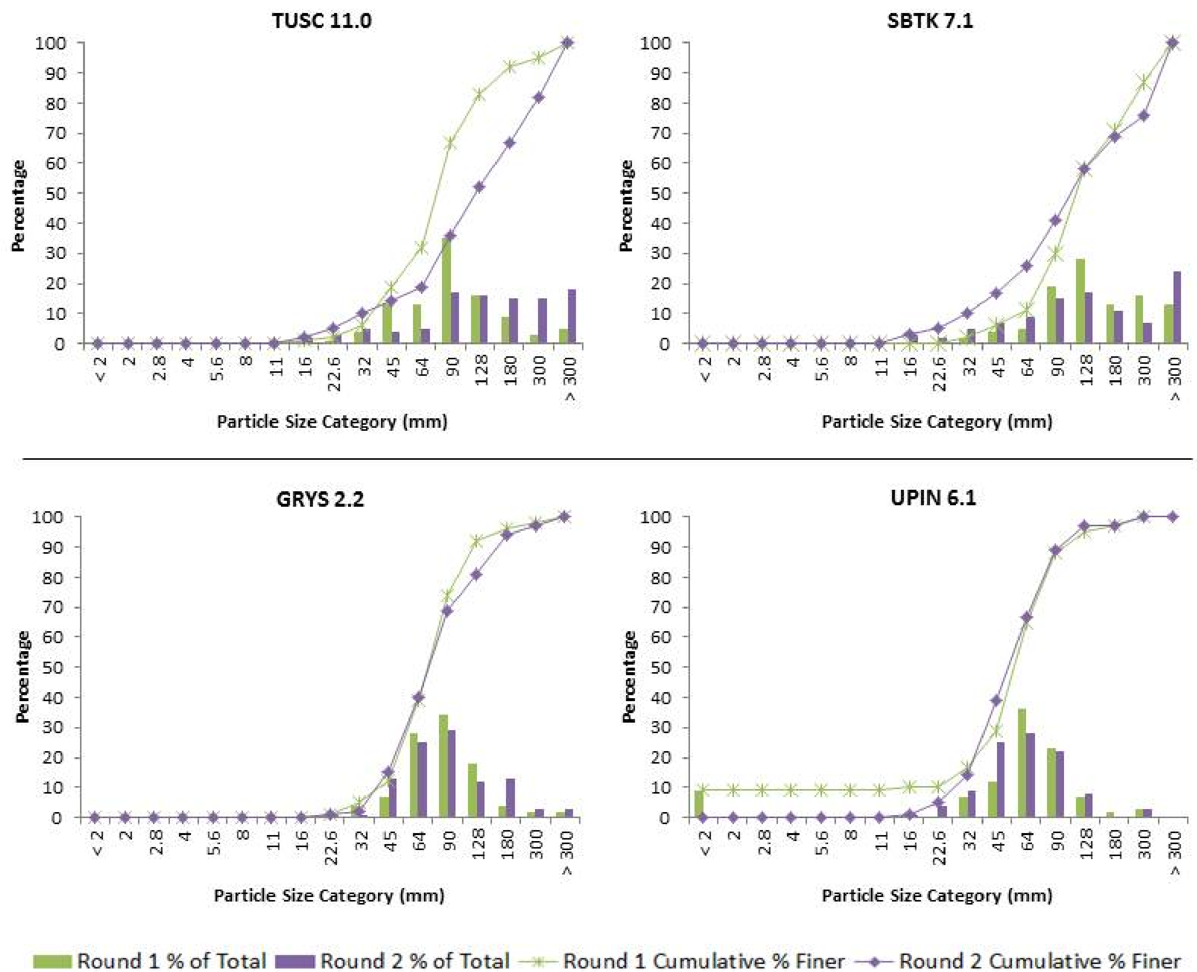

Figure 7. Substrate Particle Size Distribution (Percentage of Total and Cumulative Percentage Finer) for TUSC 11.0, SBTK 7.1, GRYS 2.2, and UPIN 6.1, Comparing Round 1 and Round 2 Pebble Count Data

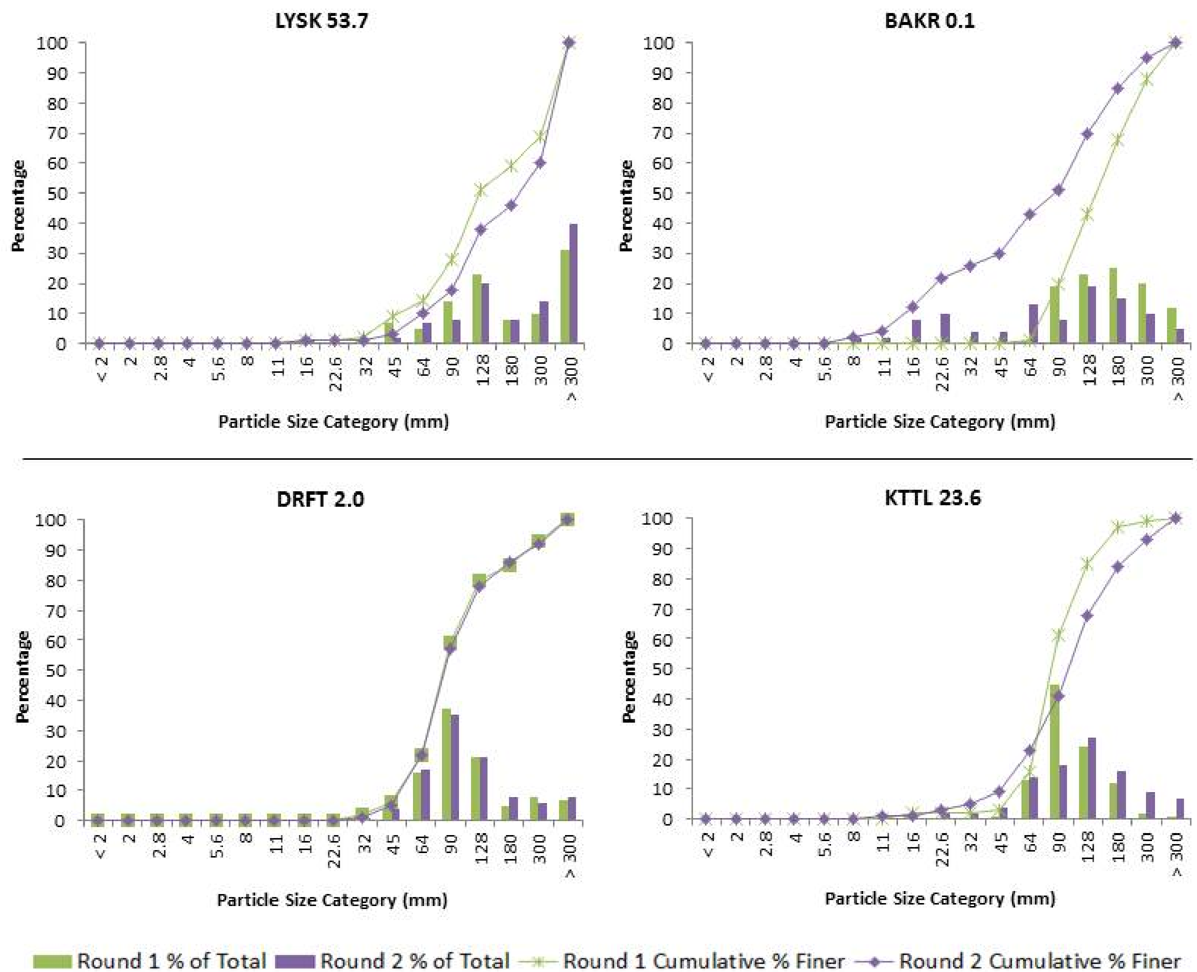

Figure 8. Substrate Particle Size Distribution (Percentage of Total and Cumulative Percentage Finer) for LYSK 53.7, BAKR 0.1, DRFT 2.0, and KTTL 23.6, Comparing Round 1 and Round 2 Pebble Count Data

bedrock. The dominant Wentworth size class (Table 2) was the same during both sampling rounds at all stations except MARS 0.8, BLLG 0.9, CATA 17.7, TUSC 11.0, SBTK 7.1, BAKR 0.1, and KTTL 23.6. The dominant size class was greater during Round 1 at MARS 0.8, BLLG0.9, and BAKR 0.1, while the dominant size class was greater during Round 2 at CATA 17.7, TUSC 11.0, SBTK 7.1, and KTTL 23.6.

Only two stations, CATA 17.7 and UPIN 6.1, had significant proportions of fine sediments (Figures 6 and 7). Fine sediments may originate from within the stream channel (i.e., unstable banks and sediment bars) or from the surrounding landscape (i.e., bare soils susceptible to erosion). The amount of sediment originating from within the stream channel is strongly tied to stream discharge and stability of the stream bed and banks. Primary within-channel sources of sediment include eroded banks, point bars, fine materials stored in interstitial spaces, backwater areas, aquatic macrophyte beds, and organic detritus. A large proportion of sediment stored within the stream channel is actually originally derived from landscape sources (Wood and Armitage, 1997). Landscape sources of fine sediments include bare soils exposed to erosion, landslides, urban runoff, and human activities such as agriculture, logging, surface mining, and construction (Richards and others, 1993). The amount of sediment that enters a stream from the surrounding landscape is controlled by land use, soil type, and vegetative cover, all of which are influenced by season and weather patterns (i.e., storm events). In the case of CATA 17.7 and UPIN 6.1, agriculture is the most likely source of fine sediments. Although agricultural land uses make up only about 17 percent of the total land use in these watersheds, agriculture is present in the immediate upstream vicinity of both of these stations.

Water Quality

Water quality was generally good among the FMN stations. Although levels of concern were exceeded for some parameters, in most cases the exceeding values were only slightly higher than natural background levels. Table 5 lists stations where water quality levels of concern were exceeded. The parameters that most often exceeded levels of concern included total orthophosphorus (14 stations), and total alkalinity (12 stations), and total nitrate/nitrite-N (10 stations). The only other parameters that exceeded levels of concern were total sodium (four stations), total nitrogen (four stations), and total phosphorus (one station). Levels of concern for total nitrogen, total nitrate/nitrite-N, and total orthophosphate are based on natural background

Table 5. Flow Monitoring Stations with Water Quality Parameter Values Exceeding Levels of Concern (Most Extreme Value in Bold Red Print)

Station Name	Date	Total Alkalinity	Total Nitrate/ Nitrite-N	Total Nitrogen	Total Ortho-phosphorus	Total Phosphorus	Total Sodium
Central Appalachian Ridges and Valleys							
WILL 0.4	06/17/13		0.67				
BOBS 11.4	06/19/13	13	0.93		0.025		
BOBS 11.4	09/04/13	18			0.037		
TSPC 0.1	06/17/13		0.75		0.032	**0.11**	
TSPC 0.1	09/11/13				**0.075**		
MARS 0.8	06/12/13				0.045		
MARS 0.8	09/16/13				0.022		
DUNN 0.1	09/04/13		0.81		0.054		
RAYS 80.5	06/24/13		**1.31**	1.31	0.048		
RAYS 80.5	09/05/13		1.10	1.10	0.055		
Northern Appalachian Plateau and Uplands							
LMEH 0.8	06/05/13				0.032		
TOBE 1.9	09/24/13				0.023		
CATA 17.7	06/05/13		0.93				
CATA 17.7	09/25/13		0.84				
TUSC 11.0	06/04/13						20.8
TUSC 11.0	09/24/13			1.30	0.022		**35.0**
SBTK 7.1	06/06/13				0.065		29.8
SBTK 7.1	09/26/13			**1.50**			26.8
North Central Appalachians							
GRYS 2.2	06/19/13	5					
GRYS 2.2	09/10/13	6					
UPIN 6.1	06/20/13	18	0.66		0.025		
UPIN 6.1	09/17/13		0.65				
LYSK 53.7	06/20/13	**4**					
LYSK 53.7	09/10/13	12					
BAKR 0.1	06/12/13	2					
BAKR 0.1	09/16/13	5					
DRFT 2.0	06/25/13	11					
DRFT 2.0	09/19/13	17					
KTTL 23.6	06/25/13	12					

concentrations rather than state or federal water quality standards because neither Pennsylvania nor New York have developed numeric standards for nutrients. Total nitrogen greater than 1.0 mg/L, total nitrate/nitrite-N greater than 0.6 mg/L, and total orthophosphorus greater than 0.02mg/L indicate enrichment above background levels. Pennsylvania has numeric water quality standards for total alkalinity and total sodium. Total alkalinity less than 20 mg/L and total sodium greater than 20 mg/L indicate possible impairment.

The highest incidence of parameters exceeding water quality levels of concern occurred at stations in the Central Appalachian Ridge and Valley ecoregion (Table 5). All stations except

BLLG 0.9 had at least one parameter exceeding levels of concern in 2013. The highest levels of total orthophosphate and total nitrate/nitrite-N were found in this ecoregion. Total orthophosphate was highest (0.075 mg/L) at TSPC 0.1 during Round 2. Elevated levels of phosphorus compounds commonly indicate excessive soil erosion, as well as pollution from wastewater and septic systems, detergents, chemical fertilizers, animal waste, and some industrial discharges. Total nitrate/nitrite-N was highest (1.31 mg/L) at RAYS 80.5 during Round 1. Common sources of nitrogen compounds include fertilizers, livestock waste, wastewater treatment and septic systems, detergents, and industrial discharges. Major sources of water quality impairment in the Juniata River Subbasin, in which all of the Central Appalachian Ridge and Valley stations are located, include agriculture (general, crop, and animal), AMD, combined sewer overflows, urban and residential runoff, industrial and municipal point sources, road runoff, and construction activities. Total alkalinity was less than 20 mg/L at BOBS 11.4 during both sampling rounds. Total alkalinity averaged 84 mg/L across the other five stations in this ecoregion. The much lower total alkalinity values observed at BOBS 11.4 are most likely due to underlying geologic formations with poor buffering capacity. There are no obvious sources of acidity in this watershed. The BOBS 11.4 alkalinity data are consistent with data collected as part of the RWQMN. The continuous RWQMN data also show periodic spikes in specific conductance at BOBS 11.4 that are currently not attributable to any known causes (Hintz, 2012).

Stations in the Northern Appalachian Plateau and Uplands ecoregion had the fewest instances of parameters exceeding water quality levels of concern (Table 5). CHOC 6.8 did not have any parameters exceed water quality levels of concern during either sampling round. Total sodium levels were slightly higher than water quality levels of concern at TUSC 11.0 and SBTK 7.1 during both sampling rounds. Possible sources of sodium include urbanization, road salt runoff, and natural gas wells, as well as natural salt deposits which could be mobilized when stream banks erode. CATA 17.7 exhibited slightly elevated levels of total nitrate/nitrite-N, which is expected given that immediate land use at this station is agricultural. Water quality findings in this ecoregion are consistent with observations from previous SRBC surveys (Buda, 2007; Campbell, 2013).

All six stations in the North Central Appalachians ecoregion had at least one parameter exceeding levels of concern (Table 5). These stations are all situated in the West Branch Susquehanna River Subbasin, which has a long history of water quality degradation, primarily due to AMD. AMD typically impacts water quality by increasing acidity (decreasing pH and alkalinity) and metals, particularly iron, aluminum, manganese, and sulfate (Kimmel, 1983). Acidic atmospheric deposition, most often related to the burning of fossil fuels, is another common problem in the West Branch. Streams impacted by acid deposition tend to have low pH and elevated aluminum levels (Sharpe and others, 1984). Although pH and metals were within the acceptable range at all stations in the North Central Appalachians, alkalinity was less than 20 mg/L at all stations. In addition to low alkalinity, UPIN 6.1 also had elevated total nitrate/nitrite-N and orthophosphorus (Table 5). This watershed has the highest percentage of agricultural lands (17 percent) among the stations in this ecoregion. The other five FMN watersheds in the North Central Appalachians have an average of 3 percent agricultural lands.

Macroinvertebrates

Non-metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity (Bray and Curtis, 1957) was used to visually examine relative similarity of macroinvertebrate communities between stations and sampling rounds (Figure 9). The stress value for the ordination was 0.171, indicating that the placement of stations on the plot may be somewhat misleading and that interpretations made based on the plot should be regarded with caution. The most obvious pattern depicted by the NMDS plot is a clear separation between sampling rounds. The plot does not show a strong pattern related to either ecoregion or drainage area; however, samples from DUNN 0.1 and RAYS 80.5 plotted close to one another. These two stations have much larger drainage areas (196 and 546 square miles, respectively) than the other large stations. The River Continuum Concept (Vannote and others, 1980) suggests that a progressive shift in structural and functional attributes of the macroinvertebrate community occurs as stream size increases due to shifts in the type and location of food resources (i.e., allocthonous versus autocthonous).

Based upon the data collected in 2013, the majority of macroinvertebrate metrics exhibited patterns related to sampling round, with metric values consistently higher during either Round 1 or Round 2 (Table 6). These patterns were observed across ecoregions and drainage area sizes. Percent eurythermal, percent cold stenothermal, percent small-bodied, and percent erosional exhibited the strongest patterns (Figure 10). The percentage of cold stenothermal individuals was higher during Round 1 at 94 percent of stations while percentage of eurythermal individuals was higher during Round 2 at 94 percent of stations. GRYS 2.2 was the single exception, demonstrating opposite patterns for these metrics. The percentage of small-bodied individuals was higher during Round 1 at 89 percent of stations, with exceptions at TSPC 0.1 and GRYS 2.2. Percent erosional was higher at 89 percent of stations during Round 2. BLLG 0.9 and LYSK 53.7 exhibited the opposite pattern for percent erosional.

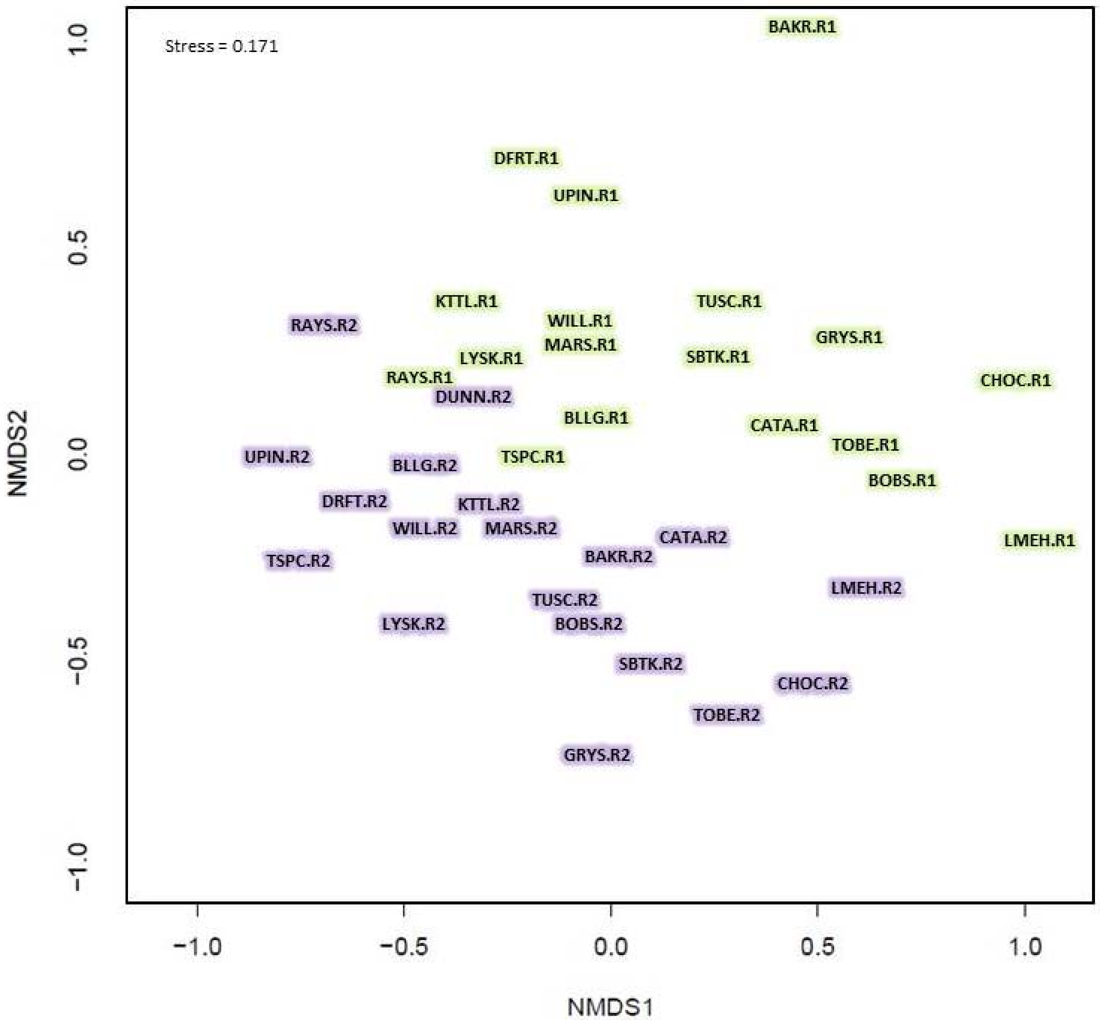

Figure 9. ***NMDS Ordination Plot Depicting Relative Similarity of Macroinvertebrate Communities Among FMN Stations (Central Appalachian Ridge and Valley stations shown in red text; Northern Appalachian Plateau and Uplands stations shown in blue text; North Central Appalachian stations shown in green text. Sampling round indicated by "1" or "2" following the four-letter stream name abbreviation.)***

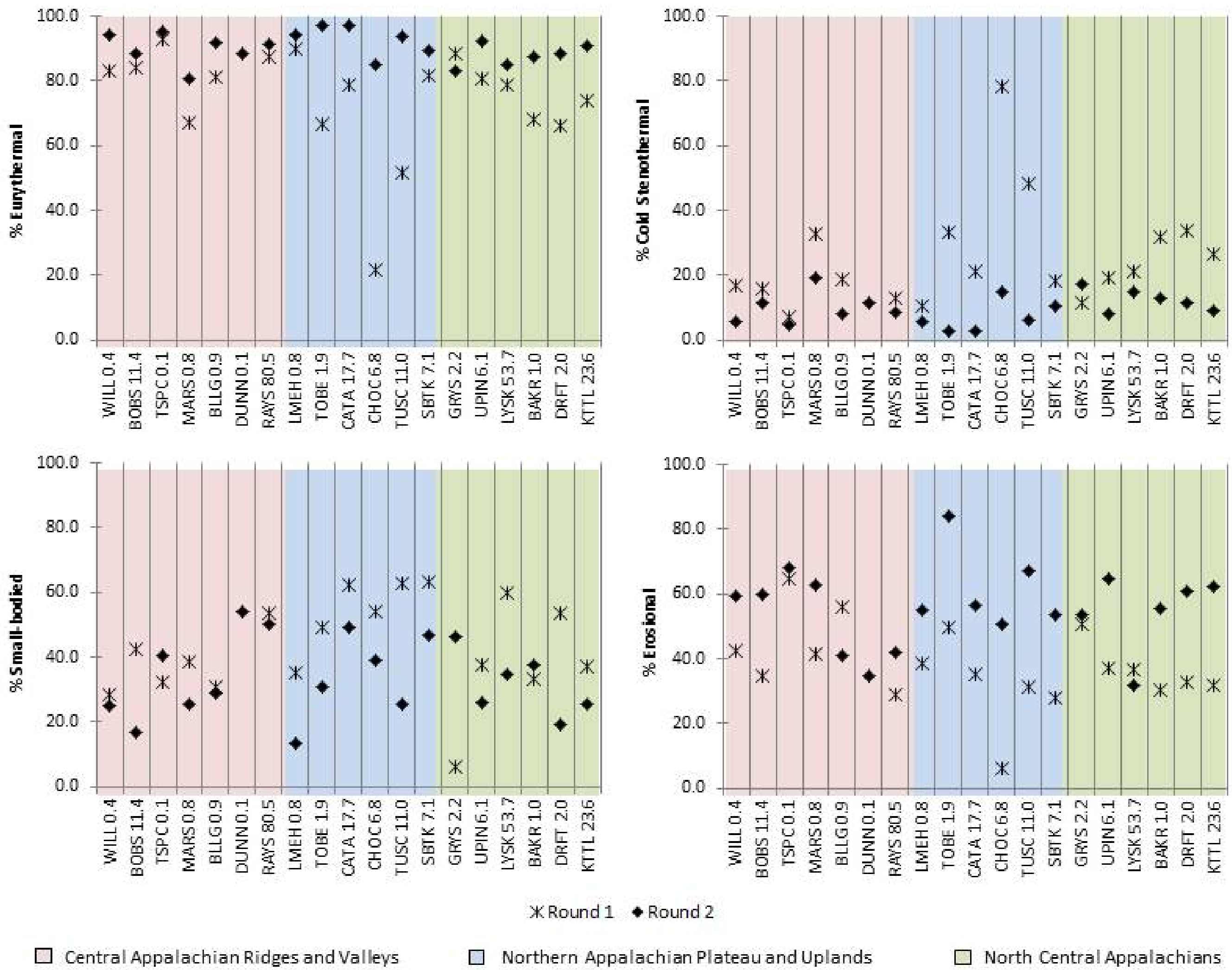

Figure 10. ***Percent Eurythermal, Percent Cold Stenothermal, Percent Small-Bodied, and Percent Erosional Individuals Found in Macroinvertebrate Samples Collected From the Flow Monitoring Network Stations***

Table 6. Summary of Macroinvertebrate Metric Trends For Flow Monitoring Network Station Samples (Red Bolded Text Indicates the Dominant Trend for Each Metric)

	Higher Round 1		Higher Round 2		Same Both Rounds	
Metric	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**
% Dominant	8	44%	9	**50%**	1	6%
% Multivoltine	9	**50%**	6	33%	3	17%
% Desiccation Tolerant	10	**56%**	6	33%	2	11%
% Strong Adult Flyers	4	22%	13	**72%**	1	6%
% Common/Abundant in Drift	7	39%	11	**61%**	0	0%
% Strong Swimmers	5	28%	13	**72%**	0	0%
% Small-bodied	17	**94%**	1	6%	0	0%
% Free-living	13	**72%**	3	17%	2	11%
% Erosional	2	11%	16	**89%**	0	0%
% Obligate Depositional	3	17%	8	**44%**	7	39%
% Shredders	11	**61%**	3	17%	4	22%
% Herbivores	13	**72%**	5	28%	0	0%
% Collector-Filterers	2	11%	15	**83%**	1	6%
% Predators	8	**44%**	7	39%	3	17%
% Eurythermal	1	6%	17	**94%**	0	0%
% Cold Stenothermal	17	**94%**	1	6%	0	0%
% Burrowers	2	11%	5	28%	11	**61%**

Other metrics that demonstrated distinct sampling round trends (more than 50 percent of stations with values higher during one sampling round) included percent dominant, percent multivoltine, percent desiccation tolerant, percent strong adult flyers, percent common/abundant in drift, percent strong swimmers, percent free-living, percent shredders, percent herbivores, and percent collector-filterers (Table 6). The only metric that had no apparent sampling round trend was percent burrowers; however, these taxa made up only a small proportion of the taxa collected across stations (0 – 3 percent of sample). Shredder taxa were also infrequently collected (0 – 18 percent of sample).

Figure 11 summarizes the benthic macroinvertebrate IBI scores from samples collected at the FMN stations in 2013. No samples were designated impaired based solely on IBI score during either sampling round, although some samples failed based on the subsequent screening questions. TUSC 11.0 failed at least one screening during Round 1 while TSPC 0.1, MARS 0.8, BLLG 0.9, DUNN 0.1, LMEH 0.8, CHOC 6.8, and SBTK 7.1 failed at least one screening question during Round 2. RAYS 80.5, TOBE 1.9, and CATA 17.7 failed to meet the requirements of at least one screening question during both sampling rounds. This indicates that despite receiving numerical IBI scores ≥ 43, the macroinvertebrate communities at these stations may be impaired. All of these stations except BLLG 0.9 and CHOC 6.8 had nutrients and/or sodium concentrations exceeding levels of concern during one or both sampling rounds (see Table 5). In addition, all of these stations except TOBE 1.9 had flows that were 10 – 91 percent lower during Round 2 than Round 1 (Table 4).

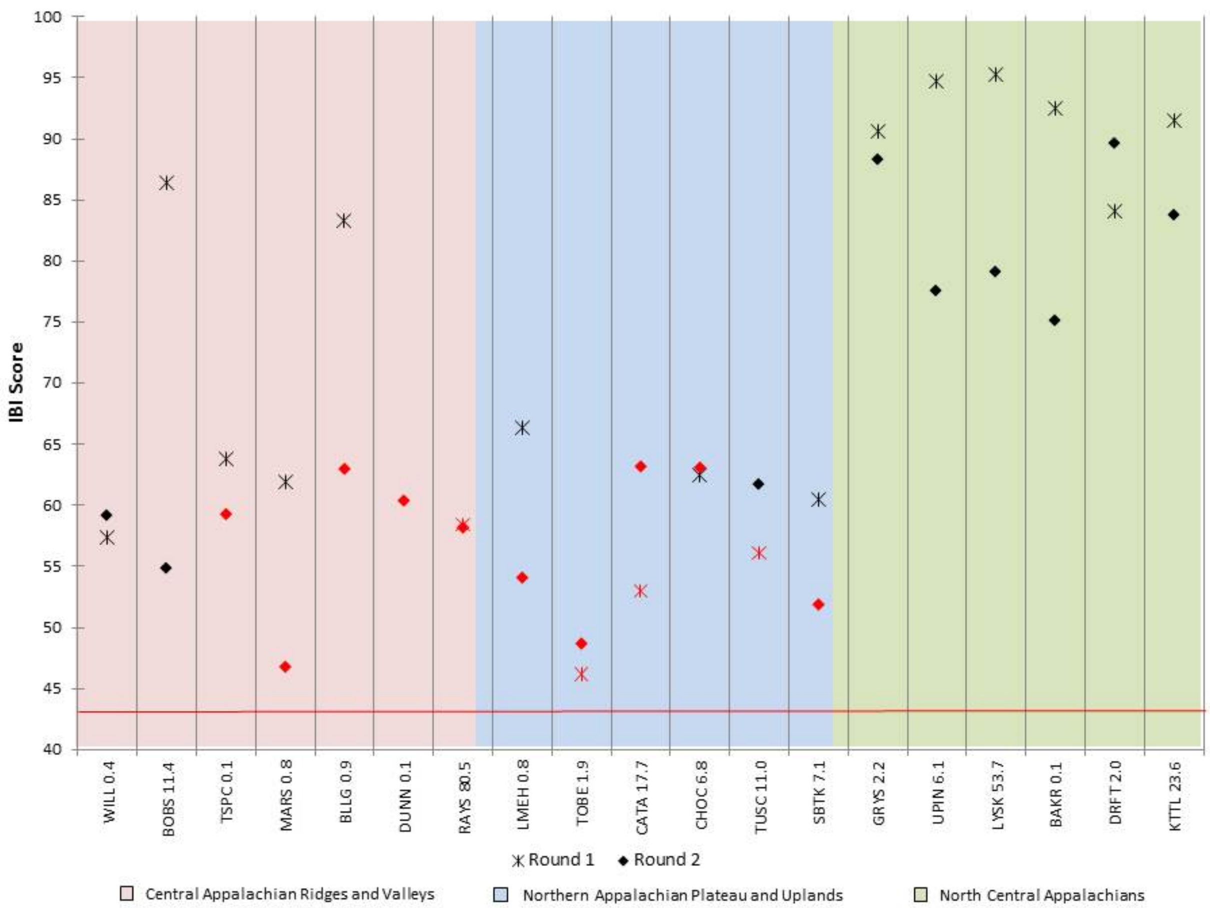

Figure 11. Index of Biotic Integrity Scores for Macroinvertebrate Samples Collected From the Flow Monitoring Network Stations in 2013 (Red Symbols Indicate Samples Failing At Least One Screening Question)

Water pollution, especially nutrient inputs, can inhibit colonization by sensitive macroinvertebrate taxa. Other sources of impairment include poor habitat conditions, particularly in the Northern Appalachian Plateau and Uplands ecoregion. Sweeney (1993) proposed that the presence of a forested buffer may be the single most important factor affecting the diversity and function of stream macroinvertebrate communities. The forest canopy shades a stream during the hot summer months, helping to regulate water temperature and provide refugia for coldwater taxa. Fallen trees and branches, as well as the root structures of living riparian trees, provide complex instream habitat for colonizing macroinvertebrates. Finally, streamside vegetation provides an allochthonous source of nutrients in the form of particulate plant matter (i.e., leaves, fruits, woody debris). Of the three ecoregions sampled, the Northern Appalachian Plateau and Uplands stations were located in watersheds with the lowest average percentage of forested lands while the North Central Appalachian watersheds had the highest average percent forested. The stations located in the North Central Appalachians ecoregion had consistently high IBI scores despite all stations having at least one water quality parameter that exceeded levels of concern during both sampling rounds, supporting the hypothesis that the presence of a forested buffer positively influences the macroinvertebrate community.

IBI scores were higher during Round 1 than Round 2 at 67 percent of stations (Table 7). Of the six IBI component metrics, Beck's Index, EPT Taxa Richness, Taxa Richness, Percent Sensitive, and Shannon Diversity Index were higher during Round 1 at the majority (greater than 61 percent) of stations. Hilsenhoff Biotic Index scores did not show a distinct pattern related to sampling round (Table 7).

The sampling round trends observed for the majority of the macroinvertebrate metrics calculated may be indicative of a seasonal difference in macroinvertebrate community composition. Lotic macroinvertebrate communities in most habitats exhibit a predictable temporal sequence of species replacement that is primarily driven by shifts in food sources (Cummins, 1974). Autotrophic production forms the major food base in the spring and summer months while detritus inputs from the riparian area support fall and winter communities (Coffman and others, 1971; Minshall, 1978). While developing the IBI, PADEP (2012) found that a transition occurs in Pennsylvania macroinvertebrate communities beginning in mid-October. This seasonal difference in community composition led the agency to outline separate IBI scoring systems for samples collected between November and May and June and September (PADEP, 2012). The agency also recommended that macroinvertebrate sampling in October be avoided due to the transitional nature of the community at this time of the year. Although both rounds of sampling at the FMN stations took place within the June to September timeframe, it is possible that changing climate trends could be causing the natural transition in the macroinvertebrate community to occur earlier. In that case, differences in macroinvertebrate communities detected between sampling rounds could be due to a seasonal shift in taxonomic composition.

Table 7. Summary of IBI Component Metric Trends For Flow Monitoring Network Station Samples (Red Bolded Text Indicates the Dominant Trend for Each Metric)

	Higher Round 1		Higher Round 2		Same Both Rounds	
Metric	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**
Index of Biotic Integrity	12	**67%**	6	33%	0	0%
Taxa Richness*	11	**61%**	6	33%	1	6%
EPT Taxa Richness*	14	**78%**	3	17%	1	6%
% Sensitive (PTV ≤ 3)*	7	39%	11	**61%**	0	0%
Hilsenhoff Biotic Index*	9	50%	9	50%	0	0%
Shannon Diversity Index*	11	**61%**	7	39%	0	0%
Beck's Index (version 3)*	17	**94%**	1	6%	0	0%

Fish

NMDS using Bray-Curtis dissimilarity (Bray and Curtis, 1957) was used to visually examine relative similarity of fish communities between stations and sampling rounds (Figure 12). The stress value for the ordination was 0.157, indicating a potentially useful representation but with some potential for misinterpretation. The Round 1 and Round 2 samples from several stations, including UPIN 6.1, LMEH 0.8, TOBE 1.9, TUSC 11.0, SBTK 7.1, CHOC 6.8, MARS 0.8, RAYS 80.5, TSPC 0.1, BAKR 0.1, and GRYS 2.2 plotted next to one another. There was also a pattern related to drainage area with the smallest stations (less than 25 square miles) appearing on the far left side of the plot, the medium-sized stations (25 – 50 square miles) plotting in the middle, and the large stations (greater than 50 square miles) appearing on the far right. Sampling round seemed to play a lesser role in fish community similarity compared to what was observed for the macroinvertebrate community (see Figure 9).

The TNC ecosystem flows report identified five groups of fish species that share life history strategies, habitat niches, or other characteristics that may make them sensitive to flow alterations (DePhilip and Moberg, 2010). Of these five groups, three are particularly sensitive to low flows, including riffle obligates, riffle associates, and coldwater species. Proportions of these three groups, as well as ten other metrics examining general assemblage composition or feeding guilds, were calculated.

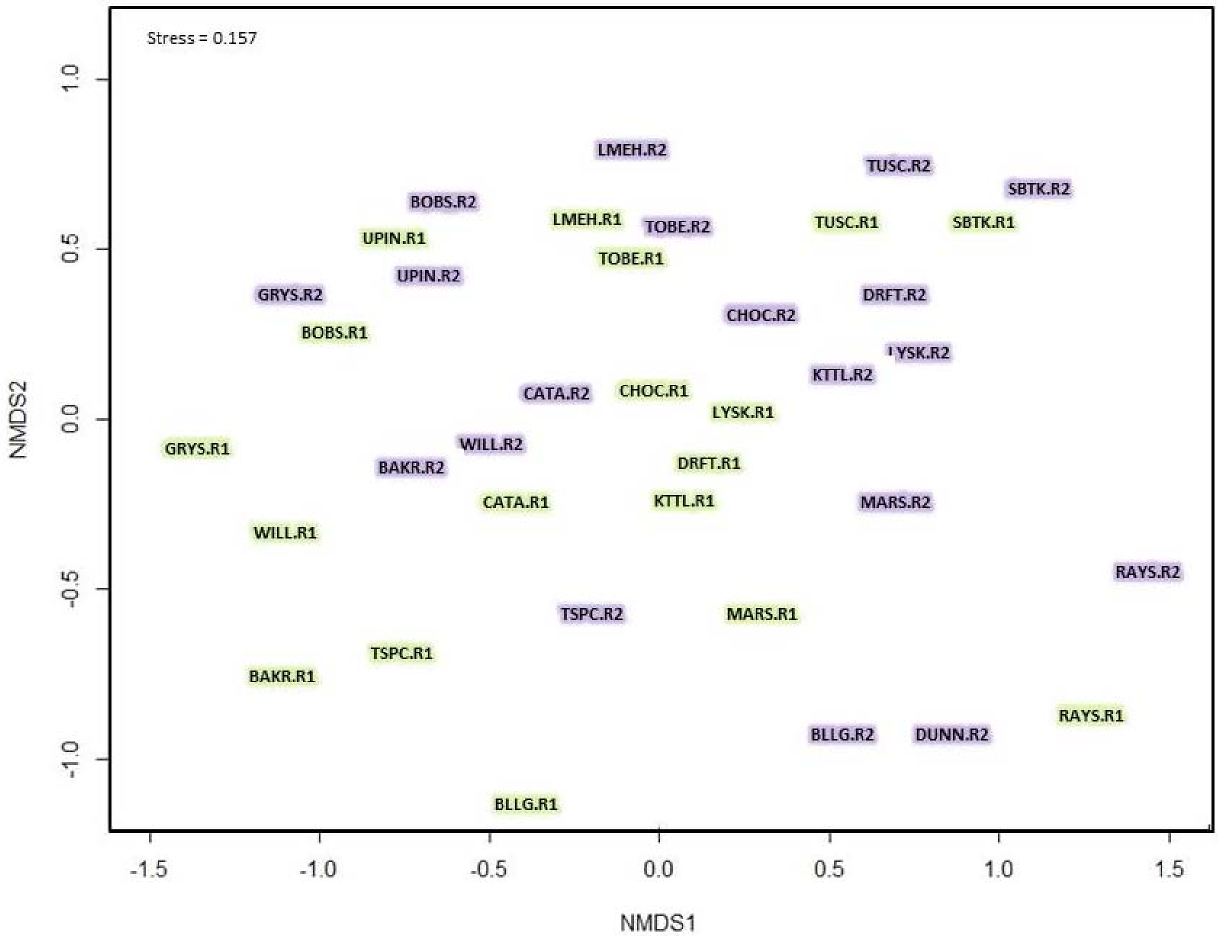

Figure 12. NMDS Ordination Plot Depicting Relative Similarity of Fish Communities Among FMN Stations (Central Appalachian Ridge and Valley stations shown in red text; Northern Appalachian Plateau and Uplands stations shown in blue text; North Central Appalachian stations shown in green text. Sampling round indicated by "1" or "2" following the four-letter stream name abbreviation.)

Based upon the data collected in 2013, the majority of fish metrics exhibited patterns related to sampling round, with metric values higher during either Round 1 or Round 2 (Table 8).The percent cyprinids metric exhibited the strongest sampling round pattern, with 83 percent of stations having higher values for this metric during Round 2 (Figure 13). Percent intolerant, percent riffle obligates, percent coldwater, percent dominant, percent insectivores, percent lithophilic spawners, and percent piscivores were higher during Round 1 at a majority of stations (Figure 13; Table 8). The following metrics tended to be higher during Round 2: percent tolerant, percent generalists, species richness, and percent riffle associates (Table 8). One metric, percent herbivores, showed no apparent sampling round trends (Table 8).

Table 8. Summary of Fish General Assemblage and Functional Trait Metric Trends For Flow Monitoring Network Station Samples (Red Bolded Text Indicates the Dominant Trend for Each Metric)

	Higher Round 1		Higher Round 2		Same Both Rounds	
Metric	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**
Species Richness	3	17%	10	**56%**	5	28%
% Tolerant	2	11%	14	**78%**	2	11%
% Intolerant	14	**78%**	2	11%	2	11%
% Dominant	12	**67%**	6	33%	0	0%
% Cyprinids	2	11%	15	**83%**	1	6%
% Piscivores	10	**56%**	4	22%	4	22%
% Insectivores	12	**67%**	4	22%	2	11%
% Generalists	3	17%	12	**67%**	3	17%
% Herbivores	1	6%	8	44%	9	**50%**
% Lithophilic Spawners	12	**67%**	6	33%	0	0%
% Coldwater	13	**72%**	0	0%	5	28%
% Riffle Obligates	14	**78%**	4	22%	0	0%
% Riffle Associates	2	11%	9	**50%**	7	39%

Although stream fish assemblages tend to be relatively stable in terms of species composition and relative abundance, they sometimes show considerable unpredictable temporal variation (Schlosser, 1990). Taylor and others (1996) found that spring and fall fish assemblages in the upper Red River basin of Oklahoma differed from one another in terms of species composition, relative abundance, and habitat usage. In the spring, the fish assemblage underwent a series of rapid shifts corresponding to high flow events. In the fall, flows were much lower and more stable, and the fish assemblage was less variable. Taylor and others (1996) also noted strong spatial aggregations of minnow species in pools during the fall while no such aggregations occurred in the spring. Matthews and Hill (1980) reported similar large aggregations of minnows during fall surveys of the South Canadian River in Oklahoma. These studies suggest that certain minnow species exhibit fall aggregative behavior regardless of flow.

Periphyton Biomass

Chlorophyll-a concentration is widely used as a surrogate for live periphyton biomass because it is the most common pigment in oxygenic photosynthesis. It is found in higher plants

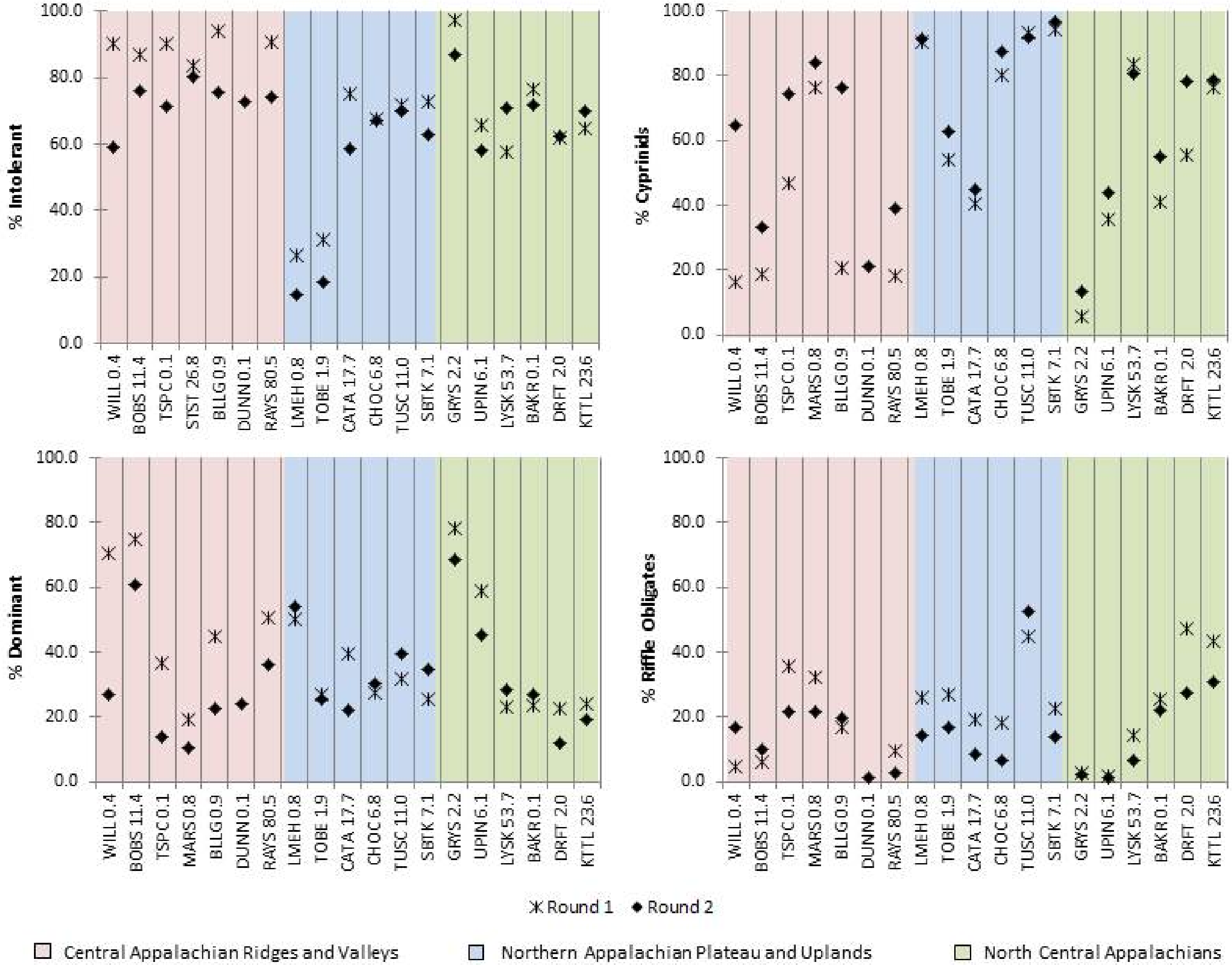

Figure 13. Percent Intolerant, Percent Cyprinids, Percent Dominant Species, and Percent Riffle Obligates Found in Fish Samples Collected From the Flow Monitoring Network Stations in 2013

as well as algae. Periphyton chl-a concentrations greater than 10 µg/cm^2 in streams are indicative of algal growth at nuisance levels (Welch, 1988) and chl-a greater than 20 µg/cm^2 indicates eutrophic conditions (Paul, 2012). Stream discharge, disturbance events, level of nutrient enrichment, light availability, and abundance of herbivores are the primary factors influencing algal biomass in lotic systems. Previous studies demonstrated seasonal changes in algal biomass ranging from many-fold to several orders of magnitude (Duncan and Blinn, 1989; Fisher and Grimm, 1988).

Periphyton chl-a concentrations exhibited a seasonal trend according to drainage area (Figure 14). Periphyton chl-a was higher during Round 1 at all of the large stations (drainage area greater than 50 mi^2) except for RAYS 80.5. Concentrations were higher during Round 2 at all of the small stations (drainage area less than 25 mi^2) sampled. Periphyton chl-a was more variable at stations of intermediate size (drainage area between 25 and 50 mi^2). TSPC 0.1, CATA 17.7, and LYSK 53.7 had higher concentrations during Round 1, while concentrations at MARS 0.8, CHOC 6.8, and BAKR 0.1 were higher during Round 2. Periphyton chl-a concentrations occurred above the nuisance level (10 µg/cm^2) at CATA 17.7, CHOC 6.8, SBTK 7.1, and UPIN 6.1 during Round 1. During Round 2, TSPC 0.1, MARS 0.8, CATA 17.7, and DRFT 2.0 had chl-a concentrations above the nuisance level. Periphyton chl-a concentration was above the eutrophic level (20 µg/cm^2) at WILL 0.4 and TSPC 0.1 during Round 1. During Round 2, only SBTK 7.1 had concentrations above the eutrophic level.

SUMMARY

Although flows at a few stations came close (i.e., WILL 0.4, TSPC 0.1, and BLLG 0.9; see Table 4), no streams in the FMN experienced ASO P95 or lower flows during the June 1 to September 30 sampling period in 2013. Data collected in 2013 provided useful baseline information about habitat, water quality, and biological conditions at the FMN stations. Should P95 flows occur in the future, these data will provide the background information regarding "normal" variations that are necessary for detecting variations caused by changing flow conditions.

Trends observed in the majority of macroinvertebrate and fish metrics suggest that these biological communities may experience natural, seasonal shifts in composition over the course of the June 1 to September 30 sampling period. Similar patterns were observed in 2012 (Hutchison, 2013). If after several years of data collection it becomes apparent that early summer and late summer/early fall biological communities are inherently different, regardless of flow conditions, sampling design and/or data analyses employed for the FMN may need to be altered.

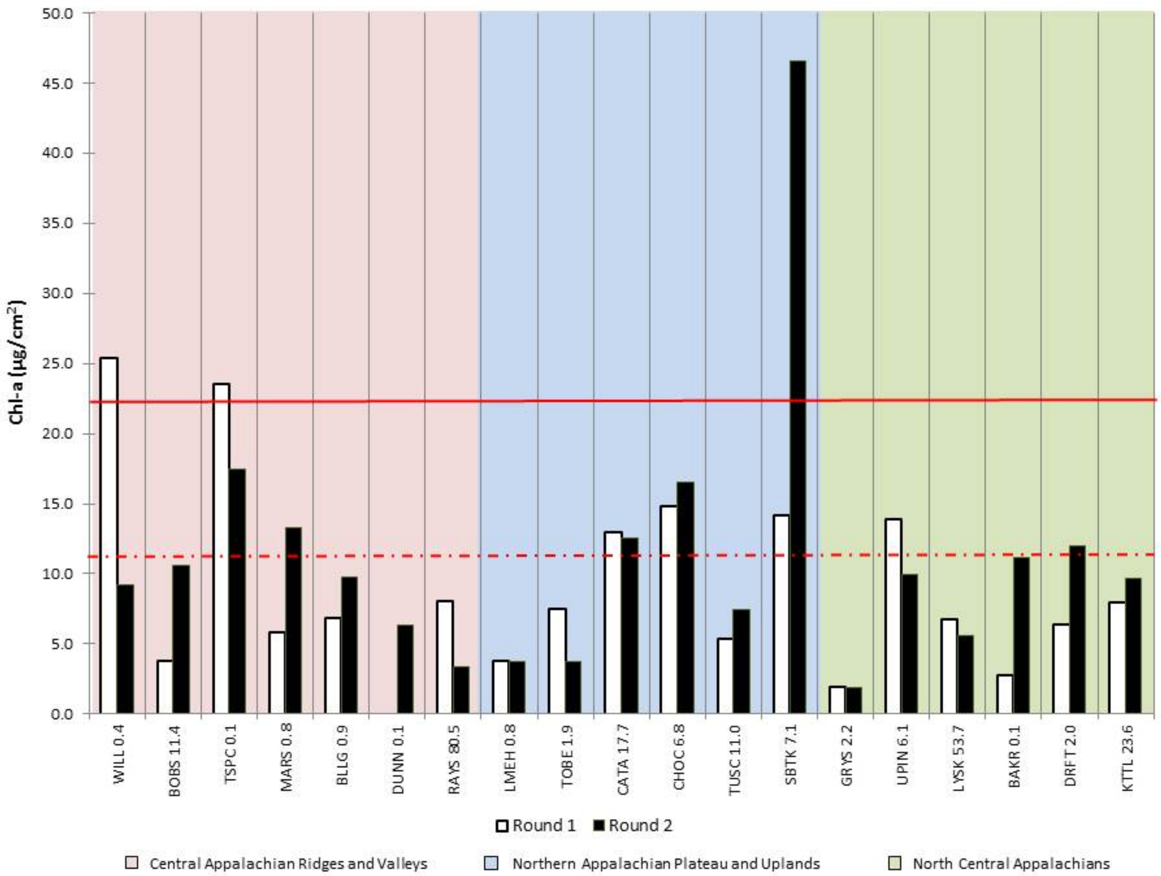

Figure 14. Chlorophyll-a Concentrations at the Flow Monitoring Network Stations (Dashed Red Line Indicates Nuisance Level of Algal Growth; Solid Red Line Indicates Eutrophic Conditions)

Preliminary rating curves for the 16 FMN stations located far from USGS stream gages have been established. SRBC staff continues to take monthly flow measurements in order to refine and improve these rating curves so that they may be used to improve the timing of sampling rounds and to allow for better correlation between flow and measured habitat, water quality, and biological parameters.

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APPENDIX A

Station Name	Location Description	Latitude	Longitude	Drainage Area (m^2)	Percent Forested	Designated Use
Central Appalachian Ridges and Valleys						
WILL 0.4	Willow Run near mouth at T305 bridge near McCullochs Mills, Juniata Co., Pa.	40.41852	-77.59602	11	93	HQ-CWF[1]
BOBS 11.4*	Bobs Creek in headwaters near Pavia, Bedford Co., Pa.	40.26388	-78.59258	17	92	HQ-CWF
TSPC 0.1	Three Springs Creek upstream of T341 near Pogue, Huntingdon Co., Pa.	40.20794	-77.94091	31	86	CWF[2]
MARS 0.8*	Marsh Creek near mouth upstream of PA150 bridge near Blanchard, Centre Co., Pa.	41.06022	-77.60997	44	88	CWF
BLLG 0.9	Blacklog Creek along T599 upstream of Rockhill and Orbisonia, Huntingdon Co., Pa.	40.24054	-77.89502	66	88	CWF
DUNN 0.1	Dunning Creek near mouth upstream of SR 1001, near Bedford, Bedford Co., Pa.	40.02433	-78.47794	196	69	WWF[3]
RAYS 80.5	Raystown Branch Juniata River upstream of Greys Run east of Everett, Bedford Co., Pa.	40.00466	-78.30017	546	70	TSF[4]
Northern Appalachian Plateau and Uplands						
LMEH 0.8*	Little Mehoopany Creek near confluence with the Susquehanna River, Wyoming Co., Pa.	41.58155	-76.07095	11	68	CWF
TOBE 1.9	Tobehanna Creek on Lamoka Lake Road near Tyrone, Schulyer Co., N.Y.	42.40430	-77.06656	17	52	C[5]
CATA 17.7*	Upper Catatonk Creek near Spencer, Tioga Co., N.Y.	42.20472	-76.47508	30	70	C
CHOC 6.8*	Choconut Creek south of Vestal, NY, Susquehanna Co., Pa.	42.01077	-76.00703	38	73	CWF
TUSC 11.0*	Upper Tuscarora Creek near Woodhull, Steuben Co., N.Y.	42.07458	-77.37898	53	42	C
SBTK 7.1*	South Branch Tunkhannock Creek near La Plume, Lackawanna Co., Pa.	41.55761	-75.77664	70	55	TSF
North Central Appalachians						
GRYS 2.2*	Grays Run near Gray, Lycoming Co., Pa.	41.44997	-77.01979	16	95	HQ-CWF
UPIN 6.1*	Upper Pine Creek upstream of confluence with Ninemile Run near Telescope, Potter Co., Pa.	41.79573	-77.76546	19	75	HQ-CWF
LYSK 53.7*	Loyalsock Creek east of Ringdale, Sullivan Co., Pa.	41.45853	-76.33172	27	86	CWF
BAKR 0.1*	Baker Run in Sproul State Forest near Glen Union, Clinton Co., Pa.	41.24566	-77.60816	35	99	HQ-CWF
DRFT 2.0*	Driftwood Branch Sinnemahoning Creek near Lockwood, Cameron Co., Pa.	41.52649	-78.27008	83	90	TSF
KTTL 23.6*	Kettle Creek at PA Fish & Boat Commission Access along PA 144, Potter Co., Pa.	41.49972	-77.77085	84	95	EV[6]

*RWQMN station

[1]High-Quality Cold Water Fishery (25 Pa. Code § 93.3)

[2]Cold Water Fishery (25 Pa. Code § 93.3)

[3]Warm Water Fishery (25 Pa. Code § 93.3)

[4]Trout Stocked Fishery (25 Pa. Code § 93.3)

[5]Supports Fisheries and Non-Contact Sports (5 NY Code § 608.15)

[6]Exceptional Value Waters (25 Pa. Code § 93.3)